AN EXPLORATION OF THE INTERPLAY BETWEEN ASSESSMENT AND MOBILE PEDAGOGIES, IN SECONDARY SCHOOL MATHEMATICS

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Pauline Wong Wing Man Kohlhoff, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Arts and Social Sciences at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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For my children, who are my joy. I have on occasion wondered about the wisdom of embarking on this journey while all three of them were still so young, but in fact, rather than the work eating in to our time together, it has been nice to just be a student and do what amounts to a really big school project alongside their posters and slide presentations. I am the luckiest mamma in the world.

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Pauline Kohlhoff

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Prologue

I once had the opportunity to participate in a truly great mathematics lesson. Aimed at Stage 3 students (Years 5 and 6), the lesson began with the premise that the students were to run a stall at a school fair, which would offer passers-by a turn at a game of chance.

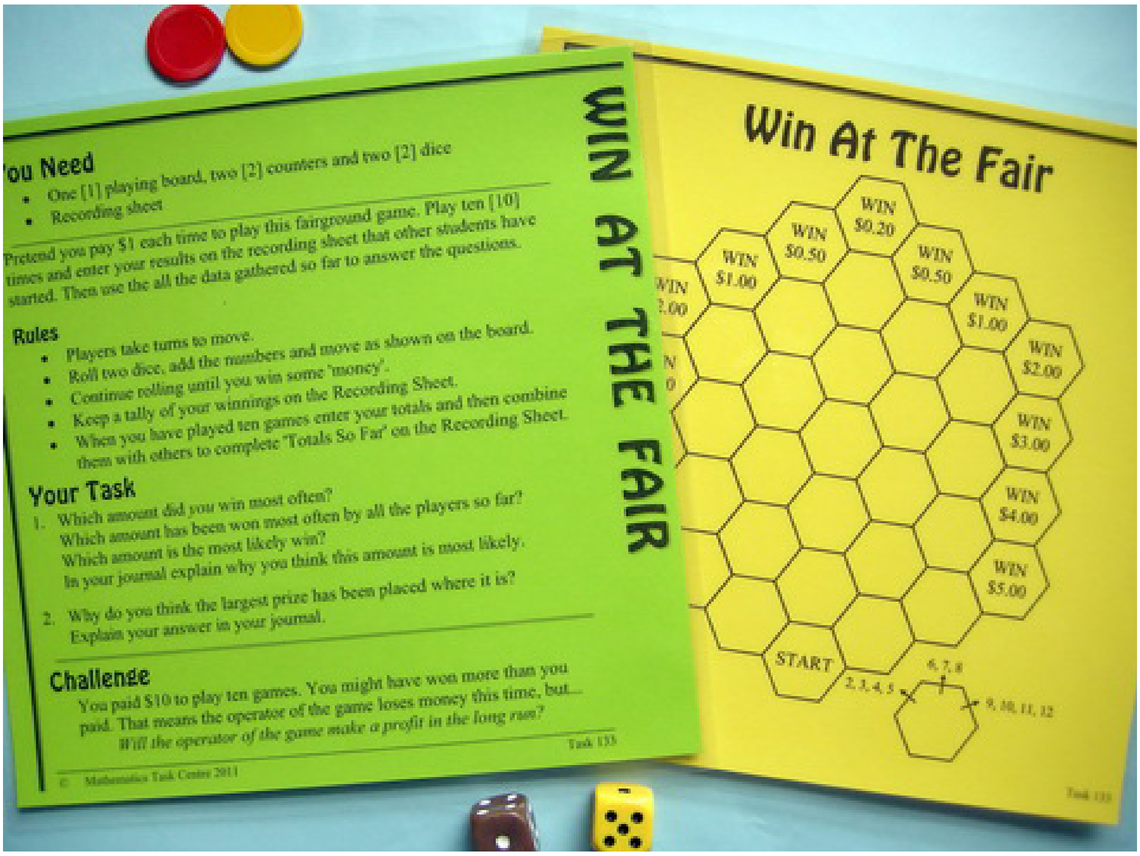
Customers would pay one dollar to be allowed to play this game, at the conclusion of which the game would “pay out” different sums, depending on the position on the board that was reached by the customer.

The teacher gathered the students around and selected one student to pretend to be a customer. The student proceeded to roll the dice and play the game to its conclusion, apparently “winning” twenty cents in the process. If this sequence of events had occurred in an actual game, then the customer would have had to pay a dollar to play in the first place, and so they would in fact have lost eighty cents; this was a point that was impressed upon the students.

The teacher then sent the students off in pairs to play five rounds of this game. Pay-out amounts were recorded on the whiteboard at the front of the room, and within ten minutes the whiteboard was covered in tally marks indicating how the students’ games had progressed.

At this point, the teacher stopped the class and asked them if they had noticed anything about the game. The class then proceeded to add up the takings from the game ($87) and then the amount the game had paid out ($124). The students were horrified - the game lost money for them! This couldn’t be allowed - the principal would be furious. Something had to be done.

The first question at this point was - well, what was a reasonable amount to pay out, on average, for every customer? The students agreed that fifty cents would be about right. The game would be profitable, but it would not be obviously taking advantage of the customers; there would still be customers who would come away happy, and who would spread the word about how great the game was. Fifty cents was considered to be a good compromise.



Game board for “Win at the Fair” (mathematicscentre.com, 2017)

The teacher then explained that the game was available online. The students could change the parameters of the game and then ask the computer to run a thousand simulated games, to see what the effect of the change might be, on the amount that was paid back out to the customers.

And so, as a class, they played around with the parameters of the game. The students changed the effect of rolling 5, so that it would cause a movement upwards instead of to the left. They changed one of the pay-out amounts down from $4 to thirty cents. With each change, they ran the simulation and checked if the average pay-out was getting any closer to fifty cents.

This lesson was run as a demonstration class at a teachers' conference in Sydney. The teacher, in this case, was Charles Lovitt; the students were all either primary school teachers or secondary mathematics teachers. At the conclusion of the activity, Lovitt explained that the purpose of the lesson was to help students understand how gambling games worked, so that, should they be faced with the prospect of playing the "pokies" at their local club, they would have an appreciation of why the game was guaranteed to lose them money. It was not, as advertised, a game of chance. Rather, it was a game of maths. Games were designed by people who understood that, in the long run, the game must have the advantage. The hope was that, through identifying with the game vendor, the students would learn that these games were rigged.

Following this, I spoke with a number of teachers who had attended that session. They - unanimously - loved it. They understood why this teaching was important, and they could appreciate the cleverness of the lesson design. They could see how all students could be engaged with this activity - after all, it only really required them to roll dice in order to be able to fully participate - as well as the scope it offered for extending the high achievers. The lesson ticked so many boxes - it was fun, it allowed the students to work collaboratively and to take charge of their learning, and the mathematics it taught was so critically important.

It also, very interestingly, used technology in a completely authentic way. The technology was used to do one of the things that technology does best: it freed the students from having to do something repetitive and time-consuming, so that they could step back and see the big picture. It was central to the lesson, but at the same time, unobtrusive.

By the end of that lesson, I had learned a lot. So, I am sure, had many of the other teachers in the room. But what I found particularly interesting about that lesson was that, even though I knew that it taught some highly relevant mathematics, and taught it very well, I could only think of one way in which we could reasonably assess the depth of that learning. To my mind, the learning from that lesson could only be assessed twenty years later, after the students had likely long forgotten a goodly proportion of their school maths - and the assessment would simply be, do they play the pokies? If they did, then the learning had apparently not occurred to the extent that was intended; and if they did not, then what were the reasons for their abstinence?

While twenty years is clearly unreasonable for the purposes of school assessment, it is my belief that an immediate short-term assessment of this learning would not have told us anything meaningful at all. A similar effect might be had from the teacher simply telling the students, “Gambling is bad” - a lesson that would take five seconds, instead of fifty minutes. How would we know? For that matter, how can we ever know how embedded the learning has become? And, as far as assessment is concerned, do we ever have the opportunity to really value such intangible characteristics of students’ mathematical thinking?

1. Introduction

If arithmetic and the sciences of measurement and weighing were taken away from all arts, what was left of any of them would be, so to speak, pretty worthless.

- Socrates*

* As quoted in Plato's Philebus 55e.

What is mathematical attainment? Skemp's (1976) article prompted considerable thought about this question when he described two fundamentally different ways of viewing mathematical understanding:

- "relational understanding" – "knowing both what to do and why"; and
- "instrumental understanding" – the ability to use "rules without reasons".

Though four decades have intervened, it is sobering to note that Skemp's perspectives remain relevant, and it would seem that this is in no small part due to some difficulties that he described for identifying underlying incentives and for assessment practices. In particular:

> *Difficulty of assessment* of whether a person understands relationally or instrumentally. From the marks he makes on paper, it is very hard to make valid inference about the mental processes by which a pupil has been led to make them; hence the difficulty of sound examining in mathematics. (p. 12)

The significance of the difficulty in assessing students' mathematical understanding becomes apparent when we consider that assessment results are widely quoted as evidence of mathematical attainment. Despite the imperfections inherent in the assessment instrument (e.g. Koretz, 2008), its results are used without qualification to describe student performance. There are then flow-on effects for determinations of educational quality, since assessment results are implicitly cited when "quality of instruction" is being discussed, irrespective of its potentially tenuous linkage with either student experience or the community's greater good. From Carroll's (1963) model listing "quality of instruction" (p. 726) as one of five factors determining learning success, to Hattie's (2003) claim that teachers account for about 30% of variance in achievement, the measure of quality in mathematics pedagogy is derived from student outcomes in assessment tasks. Thus the positioning of assessment as an arbiter of quality lends it significant weight in the educational arena, and places it as a driver of the choices made by all stakeholders in the teaching and learning process.

It is therefore unsurprising that, since quality is defined by assessment outcomes, then gains in quality are evidenced by improvements in student achievement, *as measured by assessment tasks*. Thus, despite negative connotations implicit in "teaching to the test" (e.g. Meyer, 1997, p. 296), it is taken for granted that mathematics instruction is driven by its assessment. As stated by the Gordon Commission's (2013) public policy statement:

> What we choose to assess is what will end up being the focus of classroom instruction (p. 9)

which conveniently complements the converse view,

> Students are often more motivated to learn material or methods that are of direct relevance to passing (Smith et al., 1996, p. 66);

> When there is any departure in class from the syllabus or the text, someone invariably asks whether it's going to be on the test (Thurston, 1990, p. 4).

This alignment of teacher and student interests has, at minimum, the effect of narrowing the curriculum, with the result that "many mathematics courses are specifically designed to raise scores on some standardized test" (Thurston, 1990, p. 3). Extreme reactions to high-stakes testing have even seen content reduction in subjects outside of mathematics, with rogue schools focusing exclusively on tested subjects (such as mathematics) and neglecting other parts of the core curriculum (Guisbond et al., 2013; Crocco & Costigan, 2007).

Radical cases such as these serve to highlight the potential for assessment – both high-stakes and otherwise – to distort mathematics teaching and learning. In particular, since teachers have no control over high-stakes assessment (Black, 2015), pressures from this quarter can tend to inhibit instructional choices, with teachers employing "drill and practice" instruction methods (Shepard & Dougherty, 1991, p. 12) and "teaching facts rather than teaching the children how to 'learn for themselves'" (Thompson, 2013, p. 74). Schools' and teachers' desire to be ranked highly in external tests impacts on pedagogy, even when the tests are not intended to be high-stakes (Lowrie, Greenlees & Logan, 2012).

How, then, does a secondary school mathematics teacher justify the adoption of novel pedagogies that are only obliquely relatable to external accountability and assessment? Such choices must necessarily demonstrate a strong conviction that, despite a lack of empirical evidence of gains in assessment outcomes, the pedagogy has great potential for realising meaningful benefits for teaching and learning.

The introduction of mobile learning is one example of such a pedagogical choice. To inform our discussion of this phenomenon, we shall here adopt the definition offered by Crompton, Muilenburg and Berge (2013), which sees mobile learning encompassing

> learning across multiple contexts, through social and content interactions, using personal electronic devices (p. 83)

and clarify our interpretation with the caveat that "owing to the transience and diversity of the devices ... [a technocentric definition is] too unstable" (Traxler, 2010). Therefore, for the purposes of our discussion, mobile learning simply refers to teaching and learning with personal (i.e. student-centred) mobile technologies. In essence, these are devices that are both portable (such as, but not limited to, mobile phones, tablets, and laptop computers) and able to be used for

> communication and collaboration, and for teaching and learning activities that are different from what is possible with other media.
> (University of Sydney School of Education and Social Work, 2018)

With mobile learning thus specified, we shall use the term “mobile pedagogies” to refer to pedagogies that are suitable for mobile learning (Kearney, Burden and Rai, 2015), and, like Kearney et al, we shall deliberately focus upon teachers’ current choices, irrespective of whether mobile devices are prerequisite for engaging with the pedagogies in question. Thus, for example, mobile pedagogies would encompass the practices of secondary school mathematics teachers when they promote mobile learning in their teaching.

While the introduction of mobile learning into a secondary school mathematics teaching and learning context may stem from a number of motivations, as a deliberate choice, it evinces a philosophical belief that students’ mathematical understanding will benefit from the learning opportunities that mobile technologies make possible. From a pragmatic perspective, such a choice must also consider the importance with which assessments are regarded, and that they offer an accepted means of ascertaining and communicating what students have achieved. Thus, assessment is inextricably tied to teaching, prompting analogies such as “different sides of a single coin” (Harvey & Bright, 1991, p. 52); and, in Romberg’s (1994) view, it “helps us distinguish between teaching and learning” (p. 7), with the conclusion that “in practice, one cannot divorce assessment from content or how that content is taught”.

It is therefore the case that, if mobile learning is a paradigm that does not easily reconcile with what is valued and measurable through assessment instruments (e.g. Grace-Martin

& Gay, 2001; Fried, 2008), then combining the two would see pedagogy and assessment at cross purposes.

The research presented in this thesis is positioned at this juncture. It approaches the question of introducing mobile learning from the viewpoint that assessment must keep pace with the nature of the skills that students will be acquiring - indeed, skills that students will be needing, in order to become productive citizens of an internetworked global community. The timing of this project is salient because mainstream assessment instruments have not yet undergone any substantial change in this regard. This implies that teachers who endorse and engage with mobile learning are doing so in the full knowledge that their students will, nonetheless, ultimately be required to submit to assessment using pre-mobile-learning mechanisms.

From this perspective, it is important to ground the research in the practical issues faced by teachers on a day-to-day basis. With an understanding that teachers are obliged to work within the constraints of their situation, this study does not set out to seek the blue-sky practices of mobile pedagogical pioneers. Instead, it deliberately foregrounds the issues that are faced by real teachers in real classrooms, with an aim of presenting a more authentic and realistic picture of what does occur when student-centred mobile technologies are used.

The present study is aligned with an Australian Research Council (ARC) Discovery project entitled "Mobilising secondary education: Optimising teaching and learning with mobile-intensive pedagogies". The aim of this umbrella project is to investigate the

> learning contexts, technological designs, epistemologies and pedagogies that promote or inhibit quality teaching and learning with mobile devices in schools (Aubusson et al., 2015)

with a particular focus on secondary school mathematics and science. In particular, the project asks the question:

> How can epistemological and pedagogical transformations be realised in schools to achieve quality teaching and learning using mobile technologies?

Within this project, the present study focuses on the sub-question

> What are the implications of mobile intensive pedagogies for secondary school assessment practices?

and it is with reference to this sub-question that the following research questions are proposed:

1. What do secondary mathematics teachers value in student learning with mobile technologies;
2. How do traditional mathematics assessments influence teacher perceptions of the effectiveness of teaching with student-centred mobile technologies; and
3. What do mathematics teachers perceive to be the characteristics of assessment methods that enable and encourage the use of mobile technologies?

2. Literature Review

We learn more by looking for the answer to a question and not finding it than we do from learning the answer itself.

- Lloyd Alexander

The purpose of this study is to consider the practical implications of introducing mobile pedagogies in secondary school mathematics. Why do teachers do it? How might we assess the learning? And how might our pre-existing assessment regimes affect the way that the learning is implemented?

With a topic that spans mathematics education, technological capabilities and potentialities for assessment, an examination of the current state of play requires the synthesis of a diverse range of perspectives. Since the change in the landscape is being driven by technological change, this chapter will begin by considering the nature of this change, in order to define the extent to which it can reasonably be expected to influence existing practice. Particular consideration will be given to the ability of mobile technologies to support "higher quality" pedagogical practices - that is, practices that are of interest for improving both mathematics education and the student experience.

The chapter will continue with a discussion regarding assessment, which will be considered from perspectives including its myriad purposes, methods of practical implementation, and the affective outcomes that result from the employment of particular mechanisms. The assessment focus will then narrow towards the particular pressures and complexities that arise due to the nature of mathematics content, and society's understanding of what it means to be mathematically competent. Considerations regarding what it actually means to exhibit conceptual mathematical understanding will lead to a discussion regarding assessment mechanisms that offer alternative ways of communicating the extent of a student's mathematical achievement.

Finally, a theoretical framework will be proposed for the study. Since the study focuses on teachers as they learn to navigate a changing teaching and learning landscape, Vygotskyan (1978) theories of scaffolded learning will be presented alongside modifications proposed by Valsiner (1997) to provide a structure for the description of teachers' practice.

2.1. Mobile Technologies and Learning

The introduction of mobile technologies for the teaching and learning of secondary school mathematics offers exciting pedagogical possibilities. From educational computer games (e.g. Nansen et al., 2012; Finkelberg, 2014) to interactive lectures (e.g. Balakrishnan & Gan, 2015), technology enables teachers to orchestrate learning experiences in hitherto unimaginable ways - as well as allowing the students themselves to personalise their learning:

> The aim is to design and enact not just episodic activities but ongoing programs, to gradually transform learners into more self-directed individuals being able to carry out learning tasks, not just anytime and anywhere, but perpetually and across contexts, with and without external facilitations. Mediated by technology, a seamless learner should be able to explore, identify, and seize boundless latent opportunities that his/her daily living spaces may offer, rather than always being inhibited by externally defined learning goals and resources. (Milrad et al., 2013, pp. 290-291)

Mobile learning represents a fundamental shift in pedagogical thinking, challenging both "what it means to teach and what it means to learn" (Herrington & Herrington, 2007, p. 7). It offers technological affordances that can be exploited to bring authentic learning into the repertoire of an otherwise institution-bound teaching and learning experience. It can also, however, simply offer traditional learning in a more convenient and/or accessible form. To explore this idea further, we shall initially draw upon a framework described by Patten, Arnedillo Sánchez and Tangney (2006), which comprises seven categories of mobile educational application, three of which support teaching and learning as it has traditionally been understood.

2.1.1. Mobile Technologies Supporting Traditional Pedagogies

In Patten et al.'s (2006) categorisation, mobile applications that are intended for administration (e.g. scheduling and grading), reference (e.g. dictionaries and books) and low order learning activities (e.g. drill and test) merely replicate functionality that does not require mobility. Their argument is that such applications align with an instructional and behaviourist pedagogical philosophy, with consequent questionable educational benefits.

While it is clear that mobility is not a prerequisite for such applications to be used, the availability of such applications demonstrates the versatility of mobile devices and the potential for mobile devices to support different teaching styles. As noted by Naismith et al. (2004) and Pegrum et al. (2013), mobile devices are pedagogically agnostic and thus support teaching and learning practices that include, for example, those that might be considered to be behaviourist as well as those that might be labelled as constructivist, and so on. Rogoff and Chavajay (1995) particularly note the bi-directional influences between the tool and the individual, and the ways in which individuals transform tools to suit their modes of usage. Thus when Patten et al. assert that a behaviourist approach is

> at odds with the potential of handhelds to "provide more direct ways for learners to interact with materials in an authentic learning context" (p. 301)

there is an inference that one paradigm precludes the other, but clearly it is possible for different philosophies to work in tandem. As Munter, Stein and Smith (2015) note, there are significant similarities between the direct instruction, "behaviourist" pedagogies and those of more dialogic, "social constructivist" methods of teaching, and

> it is our perception that equally thoughtful rationales have been provided for very different perspectives on mathematics instruction and that, in general, many who have participated in the debate have not adequately understood or characterized the views of those with whom they disagree ... In each case, participants in the debate are likely drawing comparisons between an ideal version of the model that they support and a diluted version of a model that they do not support. (pp. 23-24)

Thus while it may be argued that the mobile device is under-exploited when used by students to respond to class tests or look up explanations, this is no reason to dismiss the potential for mobile devices to be leveraged for more traditional, “direct instruction” methods of teaching and learning. Indeed, the use of mobile devices for such purposes can form the foundations upon which flipped learning can occur (e.g. Pearson, 2013).

While the term “flipped learning” refers to an arrangement whereby students would

> prepare for class by engaging with resources that have been pre-prepared by their teachers, and class time is used to do more targeted and individual instruction (Muir & Geiger, 2016, p. 149),

mobile technology also offers means by which the teaching methods themselves might be amenable to being “flipped”. Bower (2017) discusses the idea that, while a behaviourist approach to teaching may be particularly exemplified by quiz applications such as Quizlet (http://quizlet.com) and Kahoot! (https://kahoot.it), students can in fact use the same applications to create their own quizzes, resulting in “higher levels of production and creativity”, and promoting the idea that

> pedagogy is by no means a fixed, inherent attribute of a learning technology but rather depends on how the technology is used within the learning context. (p. 38)

2.1.2. Mobile Technologies Supporting Mobile Learning

In contrast to the aforementioned categories, applications that "leverage off the unique attributes of handheld devices" (Patten et al., p. 297) include those that support "microworld", "data collection", "location aware" and "collaborative" use cases. At this point it would be pertinent to supplement the discussion with a framework proposed by Kearney, Schuck, Burden and Aubusson (2012), which discusses mobile pedagogical choices in terms of their support for

- Personalisation, associated with learner choice, agency, self-regulation and customisation;
- Authenticity, which refers to the extent to which tasks are realistic and offer problems encountered by real world practitioners; and
- Collaboration, making rich connections to other people and resources mediated by a mobile device.

While Kearney et al.'s framework (Figure 2.1) offers limited scope for discussing the use of mobile devices for more traditional notions of teaching and learning, it represents a

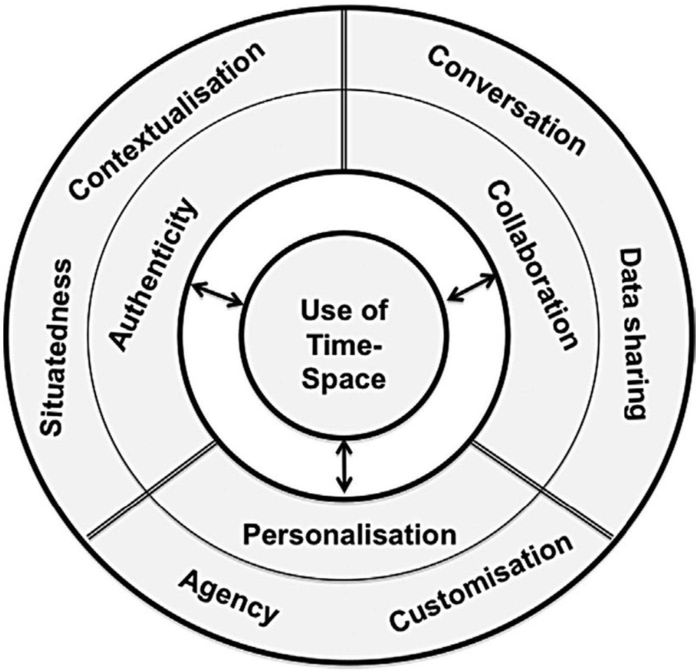


Figure 2.1. Framework for analysing mobile learning experiences (Kearney et al., 2012, p. 8)

more current and complete realisation of the characteristics of pedagogies that are truly enabled by mobility.

The use of this framework to describe the characteristics of mobile pedagogies offers an insight into the difference between what mobile devices can theoretically support, and what "mobile learning" actually means in the field. With "authenticity" being a measure of how realistic a learning activity actually is, it is sobering to note that Kearney et al.'s analysis rated many mobile learning scenarios as being obviously simulated, and the experience for students appearing to be somewhat contrived. Likewise, personalisation rated poorly in many scenarios, with students being offered limited control over their learning experience; and the collaborative aspects of the tasks tended to favour face-to-face interactions rather than communication that was particularly enabled through the affordances of the device.

While the scenarios discussed by Kearney et al. noted the existence of activities that did genuinely take advantage of these mobile learning affordances - activities that were authentic, or were able to be personalised, or were supportive of networked collaboration, it is evident that, if a teacher deliberately considers such characteristics when choosing and constructing learning experiences, then that teacher is demonstrating an awareness that these characteristics are relevant for mathematics teaching and learning. In particular, such characteristics would need to be considered for their relevance for the teaching of the mathematical concept students are expected to learn.

The difficulty at this juncture is that, due to the novel nature of mobile pedagogies, the literature linking mathematical outcomes with the affordances of mobile technology is sparse. Case studies of mobile learning initiatives (e.g. White & Martin, 2014) describe rich learning activities that are made possible by technological affordances, but tend not to discuss why outcomes from such teaching and learning are an improvement over outcomes from other approaches. Indeed, as noted by Herrington and Herrington (2007),

> While the so-called ‘early adopters’ are willing to use new technologies for pedagogical purposes, it is not yet clear that there are sound theoretical reasons for the use of mobile devices in learning (p. 1)

and even with the caveat that the goal is “improving learning, rather than proving that one pedagogical approach is more effective than another” (Herrington et al., 2009, p. 129), there is a sense that “using technology without the promise of a clear substantive benefit ought to be avoided” (Bennett, 2014, Section 13).

There are reports that such evidence is accumulating, but the results can be questionable. As an example, Cristol and Gimbert (2013) describe a study that sought to assess the effect of mobile learning on results in standardised assessments. While their quantitative analysis of the scores achieved in a single school district demonstrated statistically positive effects for all subjects except for Year 8 Math, the Cristol and Gimbert study was limited in its ability to conduct a viable statistical analysis of the effect, due to the small number of students who did not use mobile devices in class. Indeed, given the size of the population, it is unclear whether it was just one class in each case, that did not use mobile devices - and if this accurately represented the situation, then the lack of discussion regarding streaming practices raises questions regarding the relative attributes of students who did or did not engage. In any case, irrespective of the finer details of the situation in this school district, it is evidently incumbent upon proponents of mobile learning to confirm the pedagogical merits of mobile learning for improving demonstrable outcomes in school mathematics.

2.1.3. Deep Learning in Mathematics

The relationship between mobile learning and mathematics pedagogy becomes clearer when we consider frameworks for describing and evaluating mathematical learning. In particular, the Australian curriculum privileges the idea of proficiency strands which seek to describe the characteristics of mathematics learning that are valued for 21st century relevance and application:

> The inclusion of the proficiencies of understanding, fluency, problem-solving and reasoning in the curriculum is to ensure that student learning and student independence are at the centre of the curriculum. The curriculum focuses on developing increasingly sophisticated and refined mathematical understanding, fluency, reasoning, and problem-solving skills. These proficiencies enable students to respond to familiar and unfamiliar situations by employing mathematical strategies to make informed decisions and solve problems efficiently.
> (ACARA, n.d.b)

In NSW, these proficiency strands are included at the centre of the syllabus structure, comprising four of the five components of Working Mathematically. The fifth component, Communication, also exhibits clear links with the 21st century competency of collaboration.

The proficiency strands and Working Mathematically, whilst being specified in broad terms, appear to value a deeper approach to mathematical learning, lending weight to the idea that a deeper approach to learning would be associated with higher quality (Smith et al., 1996; DuFour & DuFour, 2015). This accords with taxonomies to classify mathematics assessment items as requiring “surface” or “deep” learning, including the Webb Depth-Of-Knowledge Levels (Webb, 2002, summarised in DuFour & DuFour, 2015, Chapter 1, p. 2), and the MATH taxonomy (Smith et al., 1996, p. 67), both reproduced here for comparison (Figure 2.2).

With some conceptual consistency regarding the ordering of learning objectives from “surface” through to “deep” learning, the Depth-Of-Knowledge and MATH taxonomies direct attention towards critical thinking and non-routine applications of skills. Other skills, such as collaboration, effective communication, self-directed learning and an academic mindset (Hewlett Foundation, 2012) can also be encompassed within the

Webb Depth-Of-Knowledge	
DOK 1	Recall of a fact, term, concept, or procedure - basic comprehension
DOK 2	Application of concepts or procedures involving some mental processing
DOK 3	Applications requiring abstract thinking, reasoning, or more complex inferences
DOK 4	Extended analysis or investigation that requires synthesis and analysis across multiple contexts and non-routine applications

MATH Taxonomy		
Group A	**Group B**	**Group C**
Factual Knowledge	Information Transfer	Justifying and Interpreting
Comprehension	Application in new situations	Implications, conjectures and comparisons
Routine use of procedures		Evaluation

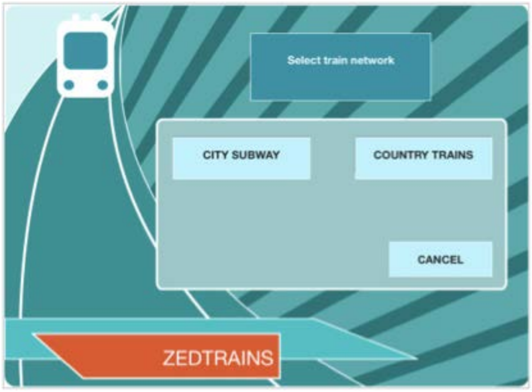
Figure 2.2. Comparison between taxonomies to classify mathematics assessment tasks.

umbrella term of "deeper learning". With clear links to the Kearney et al. framework and the affordances of mobile technologies, the valuing of these competencies offers some insight into the role that mobile learning might play in mathematics pedagogy. The appreciation that mobile learning can help to develop these skills also coincides in many ways with a push towards prioritising deeper mathematical understanding, which is being largely driven by economic considerations related to the changing nature of work:

> As computers have lowered the cost of calculation, numerical tools and models now permeate many jobs, and holding one of those jobs requires becoming a mathematics consumer. ... In most cases, a computerised tool does the actual calculation, but using the model without understanding the mathematics leaves one vulnerable to potentially serious misjudgements (OECD, 2012b, p. 31).

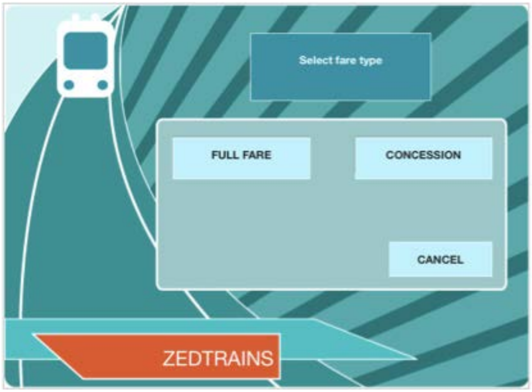
With increasingly sophisticated computer technology reshaping the mathematical competencies valued by society (Mahajan, 2014), it is clear that today's mathematics education must increasingly value depth of understanding; although, as noted by Skemp (1976), it is difficult to assess for this deep, "relational" understanding in such a way that it is distinguishable from the mere demonstration of procedural, "instrumental" knowledge. However, the recognition that assessments must value this deep learning has led to the introduction of "increased rigor" in the assessment for the Common Core State Standards (CCSS) in America, affecting all students in tested grades beginning with the 2014-2105 school year (DuFour & DuFour, 2015). While this push towards the assessment of deep learning is understandable, the combination of this value judgement with the practical limitations associated with large-scale deployment has led to a design that remains relatively crude. To illustrate this trade-off, we shall consider a question that purports to assess for deep problem-solving skills through a mass-distribution mechanism – in this case, a sample question from PISA Problem Solving 2012 (Figure 2.3).

TICKETS



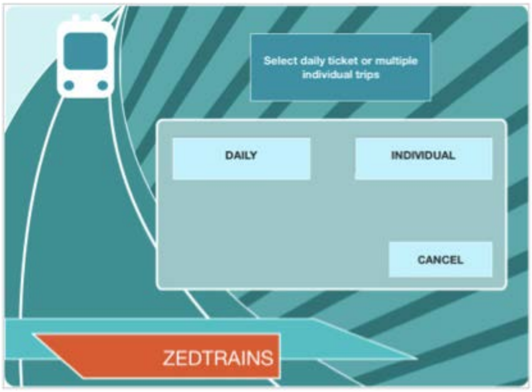
A train station has an automated ticketing machine. You use the touch screen on the right to buy a ticket. You must make three choices.

Choose the train network you want (subway or country).



Choose the type of fare (full or concession).

Choose a daily ticket or a ticket for a specified number of trips. Daily tickets give you unlimited travel on the day of purchase. If you buy a ticket with a specified number of trips, you can use the trips on different days.



The BUY button appears when you have made these three choices. There is a CANCEL button that can be used at any time BEFORE you press the BUY button.

Question TICKETS

You want to buy a ticket with two individual trips for the city subway. You are a student, so you can use concession fares. Use the ticketing machine to purchase the best ticket available.

Once you have pressed BUY, you cannot return to the question.

Figure 2.3. Context from PISA Problem Solving 2012 sample question (OECD, 2012a).

The question is designed to elicit a "problem solving" response, and to this end, it presents a problem: it is not possible to purchase the ticket as specified (Figure 2.4 and Figure 2.5).

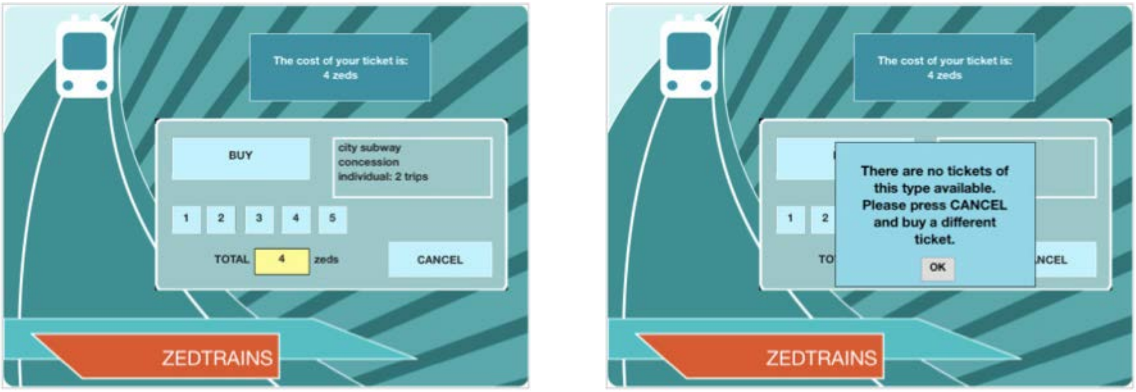


Figure 2.4. "Problem-Solving" screens from PISA 2012 sample question.
(OECD, 2012a)

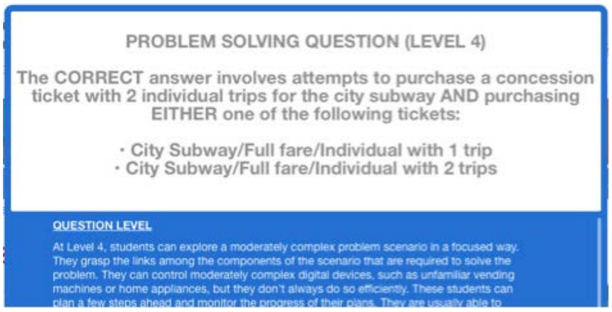


Figure 2.5. Solution for PISA Problem Solving 2012 sample question.
(OECD, 2012a)

That the question's "correct" answer involves purchasing a more expensive ticket than that to which the student is entitled, demonstrates an attitude that is not necessarily shared by all students. The inflexible nature of such one-sided interactions has a long tradition; indeed, given the black-and-white nature of "correct" mathematics responses, issues with "realistic" contexts are unsurprising, and students' applications of common sense, as would occur in real-world situations, do not necessarily lead to the sought-after conclusions (Boaler, 1994).

Thus, while tests of low-level academic content are considered to be flawed, there may be some difficulty in constructing unbiased assessment tasks to determine whether deep learning has actually taken place. Indeed, different values can inform individual views regarding the confluence of mathematics, deep learning and problem interpretation, with “mathematics education” meaning different things to different people, and varying values being placed on the skills required to solve mathematical problems. Between Archbald and Newmann (1988):

> ... we must be careful to see that assessment exercises are driven by the human purposes we want education to serve. ... Such assessments should consider tasks that meet at least three criteria: disciplined inquiry, integration of knowledge, and value beyond evaluation (p. 1)

and Thurston (1990):

> Mathematics has a remarkable beauty, power, and coherence, more than we could have ever expected. It is always changing, as we turn new corners and discover new delights and unexpected connections with old familiar grounds. [...] the aesthetic goals and the utilitarian goals for mathematics turn out, in the end, to be quite close. Our aesthetic instincts draw us to mathematics of a certain depth and connectivity. The very depth and beauty of the patterns makes them likely to be manifested, in unexpected ways, in other parts of mathematics, science, and the world.
>
> To share in the delight and the intellectual experience of mathematics - to fly where before we walked - that is the goal of a mathematical education (p. 8)

there may be little real disagreement, and yet the emphasis, for demonstration of deep learning, would differ considerably. Real-world application does not easily coexist with objectiveness and purity, whether for mathematics education or otherwise.

The context for the assessment of deep learning is therefore determined by the nature of the understanding that is being valued, and it is here that we see differences between the Webb Depth-Of-Knowledge and MATH taxonomies. While they appear to be in close agreement regarding what constitutes low-level knowledge, Webb's (2002) illustration of Level 4 "Extended Thinking" provides the following example:

> ... if the student is to conduct a river study that requires taking into consideration a number of variables, this would be a Level 4. At Level 4, the cognitive demands of the task should be high and the work should be very complex. Students should be required to make several connections - relate ideas within the content area or among content areas - and have to select one approach among many alternatives on how the situation should be solved, in order to be at this highest level. Level 4 activities include designing and conducting experiments; making connections between a finding and related concepts and phenomena; combining and synthesizing ideas into new concepts; and critiquing experimental designs. (Mathematics Depth-of-Knowledge Level 4)

This contrasts with Smith's (1996) examples of Group C tasks, which include:

- proving a theorem in order to justify a result, method or model;
- the ability to make conjectures based, for example, on inductive or heuristic arguments, and then to prove these conjectures by rigorous methods;
- the construction of examples and counterexamples;
- creativity, which includes going beyond what is given, restructuring the information into a new whole and seeing implications of the information which is not apparent to others. (p. 70)

The discussion of the potential for mobile learning activities to facilitate the development of deep mathematical learning necessarily requires a stance on what deep learning implies. The comparison between the Webb Depth-Of-Knowledge and MATH taxonomies serves to illustrate that, even with fundamental agreement on what deep learning is not, the problem of what it is, remains largely open to interpretation. The question of how to assess for it is therefore a function of the priorities either espoused or negotiated by the educational system overseeing its implementation.

2.1.4. Assessment as Motivator

The content emphasis for the purposes of "deep learning" is also disputed for the purposes of student motivation. With Brophy's (1999) motivationally optimal learning situations arguing for students to "value what they are learning for its perceived self-relevance and potential life application (not just to enjoy the activities in which they are engaged)" (p. 85), contrasting with Hickey and Zuiker's (2005) appeal to seek educational content from the practices of "motivated knowledge communities" (p. 285), the practical, everyday relevance of mathematics is once again juxtaposed against the beauty of the mathematics that appeals to the interest and natural curiosity of mathematicians.

The potential for increased student motivation and engagement provides much of the impetus for the introduction of student-centred technology (e.g. Anastopoulou et al., 2012). Thus the question of what really motivates students is particularly salient, and it is here that the motivating nature of assessment must be acknowledged (e.g. Bolton & Elmore, 2013; Anderman et al., 2010). In particular, the use of assessment to maintain student motivation has been found to be relevant to engagement with online tasks, with Churchill (2009) noting that, while his students recognised that blogging "facilitated and contributed to [their] learning" (p. 181), they were far more willing to blog in the future if it comprised part of their course assessment.

As an externally imposed construct, assessment as motivator is undoubtedly artificial, contrasting directly with intrinsically motivated activities. By way of illustration, reading a self-selected book may have primarily intrinsic value, not requiring an external purpose and not conducted within an "achievement situation" (Brophy, 1999, p. 75), and thus differs from learning situations that seek to achieve explicit goals. With motivating factors ranging from direct financial incentives for achievement (Fryer, 2011), to the ecstatic state of being in "flow" (Csikszentmihalyi, 2004), assessment by a party external to oneself would tend towards the former, being simultaneously more contrived and less personal; and with blatantly market-oriented measures showing statistically zero positive effects in student achievement (Fryer, 2011), it is clear that the relationship between pedagogy, motivation and assessment requires more nuanced manipulation than the mere application of external incentives.

2.1.4.1. Goal Theory

It is at this point that goal theory provides a perspective on achievement and how it is conceived by the students themselves (Dweck & Leggett, 1988). Anderman et al. (2010) summarise goal theory's two main classifications thus:

> **Mastery goals:** [A] student who endorses a mastery goal is interested in engaging with the task at hand; such students use themselves as points of comparison to define their achievement and are concerned with self-improvement (Can I do better this time than I did last time?).

> **Performance goals:** Most researchers discuss performance goals in terms of performance-approach goals (i.e., the goal of demonstrating one's ability relative to others) and performance-avoid goals (i.e., the goal of avoiding appearing incompetent or lacking in ability). (p. 124)

Achievement in summative assessments necessarily involves the demonstration of one's competence. Thus, summative assessments promote a performance goal mindset, with "the results [being] students who are more extrinsically motivated and not internally driven" (Bolton & Elmore, 2013, p. 131); and while this is directly associated with patterns of helpless, maladaptive behaviour (Dweck & Leggett, 1988), economic considerations lead inevitably to the conclusion that summative assessments are unavoidable. While university places and other valued resources are finite, a system must exist to determine how they are awarded; and to this end, high-stakes examinations, such as at the end of secondary school in many jurisdictions, act as a mechanism to objectify the ranking of examinees.

It should be noted that there exist examples of college admission which bypass the high-stakes examinations system:

> To address one common fear, the graduates of grade-free high schools are indeed accepted by selective private colleges and large public universities - on the basis of narrative reports and detailed descriptions of the curriculum (as well as recommendations, essays, and interviews), which collectively offer a fuller picture of the applicant than does a grade-point average. Moreover, these schools point out that their students are often more motivated and proficient learners, thus better prepared for college, than their counterparts at traditional schools who have been preoccupied with grades (Kohn, 2011, "Deleting – or at least Diluting – Grades", para.4)

and yet a summative judgement must, at some stage, occur. “Replacing letter and number grades with narrative assessments or conferences” (Kohn, para.2) does not obviate the need to rank students seeking entrance to university.

Indeed, Sahlberg’s (2015) description of Finland’s National Matriculation Examination illustrates that high-stakes assessments at this stage are inescapable:

> [Teachers in Finland are] expected to exercise their full professional knowledge and judgment both independently and collectively in their schools. They control curriculum, student assessment, school improvement, and community involvement ... Finnish teachers, in contrast to their peers in so many countries, have the latitude and the power to follow through. (p. 9)

Thus it is significant that, despite the Finnish teachers’ frequent criticisms of the effect that high-stakes examinations have on curriculum and instruction (p. 31), the matriculation examination continues to exist, and remains an accepted feature of the Finnish education system.

With mastery-oriented individuals demonstrating heightened problem-solving strategies and markedly more effective functioning in the face of difficulty (Dweck & Leggett, 1988), there are clear benefits for mathematics education when mastery goals are encouraged at the expense of performance goals. That a performance goal mindset is promoted by summative assessment practices implies that mathematics teaching and learning suffers when there is a prospect of summative judgement; and while proponents of “de-grading schools” offer student self-assessments as a viable alternative (e.g. Bower, 2013; Kohn, 2011), such artefacts must necessarily be subject to personality bias. In particular, Boud and Falchikov’s (1989) analysis of studies of student assessment noted that

> "good" students tended to underrate themselves compared to staff marks, whereas "weak" students tended to overrate themselves. (p. 540)

That observation notwithstanding, with "no consistent tendency to over- or underestimate performance" (Boud & Falchikov, 1989, p. 543), a case might be made for the employment of self-assessment; and yet it is inconceivable that students would spontaneously develop a sense of what level of performance would demonstrate a particular level of attainment. That students were able to self-assess with some degree of consistency indicated that they had internalised a fund of knowledge regarding quality of workmanship, which was most likely acquired through experiences of being assessed by someone with more experience or content knowledge. Indeed, the judgement of an authority figure is a necessary component when evaluating a student's performance, as identified in Webber and Wilson's (2012) conversation with a student's mother:

> "I would love to be able to look at everyone from the class and see if the benchmark is with everyone else. I'm envious of the teachers in that because they know so much more about what is at that level developmentally." (p. 32)

Performance goals are not, however, necessarily normative; students may seek to succeed in absolute terms, and not value or devalue their achievement through comparisons with peers (e.g. Mora, 2013).

2.1.4.2. Mastery Goals In Practice

Implications of Removing Evaluations

A link between objective evaluations and mastery goals is offered by Ferguson (2013), who eliminated grades for a seventh-grade history class. Initial resistance and confusion ("How will my parents know if I am a good student?") demonstrated that the students' motivation “had nothing to do with intrinsic learning and everything to do with adult affirmation” (p. 197); and, following acceptance of the class structure, students began to relax “not into their learning, but away from it” (p. 200). In juggling their many graded classes with the one ungraded class, students

> chose, more often than not, to put their attention toward the graded one. In their overall world of school, the grades mattered, which meant that the ungraded one necessarily did not, or at least not as much; they were following the training on how to be successful in school that they knew. (p. 201)

One of the units of work for this class required memorisation, and so Ferguson set an activity where students would learn some information and write it out, from memory, in class.

> After they were finished, we went over the answers together. Because the goal was mastery, I had them evaluate their answers [with stars for answers that were completely correct]. ... When we finished going over the answers, they immediately added up the number of correct responses that they had and graded themselves.
>
> They suddenly were greatly agitated. They felt judged by the number of stars they did or did not have.
>
> “This isn’t fair. This class doesn’t get grades. How can you give us a quiz?”
>
> “Are you going to tell our parents?”
>
> “Do we have to turn this in?” (p. 200)

It was through this incident that the students began to understand that they were responsible for their learning:

> ... they had felt comfortable with actually not doing the work that they would have done for a “real” quiz. ... [W]hen they realized that they themselves could see their success or lack thereof, they didn’t like it. ... They began to see that they actually wanted to reach mastery. They liked to be successful and know the material; they didn’t want to fail, with or without a grade. They wanted to learn. It was important to them. (p. 200)

In subjecting themselves to an objective evaluation, Ferguson’s students began to appreciate that mastery was a worthwhile goal, but even so, had “little or no choice on where to put effort”: the fear of a bad grade in another subject was a more insistent call than the attainment of mastery in History. A solution was reached whereby students collaboratively developed their own routines to “give them guidance without the fear”, in order to limit the effect of external obligations on their learning for this class.

> Their first idea surprised me: They wanted quizzes and even tests periodically, because it gave them a sense of accomplishment to know that they had control over a body of information. They wanted to be able to retake any one in which they didn’t feel they had showed mastery. They only wanted two more chances; then they felt it should be time to move on. They wanted some homework, but not too much. If they didn’t get it done, they wanted another day with no consequences. They thought that their parents should be contacted only after three homework assignments had not been turned in or after three tries on the test didn’t show mastery. As they talked, it was clear that they wanted to hold themselves accountable in ways that would push them to do their best work over time. (pp. 201-202)

Retakes and Resubmissions

The retaking of tests and resubmission of assignments offers further possibilities for the demonstration of mastery. Wormeli (2011) described ways in which multiple attempts could be managed fairly and equitably, and always with an eye towards the "supreme goal" of learning.

Wormeli's argument was that, not only should redos and retakes be permitted, regardless of the student's transgression, but the student should receive full credit for a subsequent successful attempt. He cited adult competency tests for comparison:

> LSAT. MCAT. Praxis. SAT. Bar exam. CPA exam. Driver's licensure. Pilot's licensure. Auto mechanic certification exam. Every one of these assessments reflects the adult-level, working-world responsibilities our students will one day face. Many of them are high stakes: People's lives depend on these tests' validity as accurate measures of individual competence. All of them can be redone over and over *for full credit*. Lawyers who finally pass the bar exam on their second or third attempt are not limited to practicing law only on Tuesdays or only under the watchful eye of a seasoned partner for the duration of their careers. If an assessment of competence is valid, achieving its passing scores grants the assessed individual full rights and privileges thereof. (p. 24, italics in original)

Thus the creation of a culture in which redos are not only permitted, but required, provided a basis for the confluence of performance and mastery goals; and student comments such as

> "Mr. Wormeli makes you do it over and over again until you learn it. It sucks!" (p. 26)

offered indications that fair treatment for high-achieving students was unlikely to be an issue.

2.2. Facets of Assessment

The preceding examples of assessment practice demonstrate different potentialities for flexibility in assessment, and serve to promote the idea that a single assessment instrument may, in the hands of different practitioners, take on a multitude of roles - only one of which might be summative judgement. Here, “summative” is generally contrasted against “formative”, the former being a final performance determination, and the latter intended solely for the provision of “feedback and correctives at each stage in the teaching-learning process” (Bloom, 1969, p. 48). However, “summative” and “formative” are not characteristics of the assessment instrument per se; and indeed, as argued by Wiliam (2011):

> Describing an assessment as formative is, in fact, what Gilbert Ryle (1949) called a “category error”: the error of ascribing to something a property that it cannot have, like describing a rock as happy. Because the same assessment can be used both formatively and summatively, the terms formative and summative make much more sense as descriptions of the function that assessment data serve, rather than of the assessments themselves. (p. 38)

Assessment delivery is necessarily coloured by its intended purpose, and, as Ferguson’s (2013) example shows, the purpose is liable to be misinterpreted and must therefore be made explicit. However, Wormeli’s (2011) practice blurs the assessment mechanism’s purpose to the point where either student or teacher may choose to retrospectively modify its intention. The assessment process starts off as wholly summative; but dissatisfaction with the grade can lead to a renegotiation of its status. The summative assessment (a poor grade) then transforms into a formative assessment (feedback regarding areas in which to improve); and, provided that the student resubmits the assessment, the original summative judgement is discarded in its entirety.

2.2.1. Rubrics

An intermediate position between unlimited resubmissions and immediate summative judgement may therefore be occupied by practical mechanisms such as rubrics, which elucidate success criteria and can help students to understand the level at which they are expected to achieve. As quoted in Arter and Chappuis (2006, p. 4), “students can hit any target that is sufficiently clear and that holds still for them”; and if Wormeli’s position regarding resubmission is tenable, then rubrics may offer similar clarification of what satisfactory work may entail, prior to the assessment’s initial submission.

Arguments against rubrics are comparatively rare, but dissenters note that it objectifies and depersonalises student work:

> “I remember the first time that grading rubric was attached to a piece of my writing. Maybe it was in 3rd grade. Suddenly all the joy was taken away. I was writing for a grade - I was no longer exploring for me. I want to get that back. Will I ever get that back?” (as quoted in Olson, 2006, para.1);

and while a loss of spontaneity and creativity may result, it remains that success criteria must exist if students are “to learn the content and skills that society identifies as important” (Wormeli, 2011, p. 26). When student work is produced as part of a teaching and learning exercise, it would be reasonable to expect practical aspects of teaching and learning - including attempts to quantify and judge the work - to intrude. The application of a grading rubric merely serves to make this process more transparent, resulting in increased student empowerment:

> I want to make sure that students are very clear as to my expectations for tests and projects. To do that I provide my students with clearly worded guidelines for projects. For the projects, I have built-in checkpoints where I check to see if

> students are on track. If it is a group project, I assign different roles to each student to assure that each student is participating in the process. While all this structure may seem controlling, it is ultimately freeing since students can relax knowing what my expectations are. (as quoted in Bolton & Elmore, 2013, p. 136)

A particular advantage of rubrics over Wormeli's resubmission method may be a more manageable time component. Stiggins et al.'s (2004) assertion that "students can hit any target they can see that holds still for them" offers some indication that, by providing an explanation of what students are expected to produce, rubrics can reduce the need for resubmissions by helping students to engage more productively with assessment tasks.

With the perspective that "[t]he recursive nature of successful learning shouldn't be discarded because it's inconvenient or we haven't figured out how to do it logistically", Wormeli touches on a pressing objection to requiring student resubmission of unsatisfactory work: the teacher will have to mark the same student's work multiple times. For individuals with limited time, unlimited marking is unlikely to be appealing, particularly when coupled with the negotiation of assignment submission:

> I was tired of laboring through hours and hours of marking, and I hated nagging kids to complete their homework (Bower, 2013, p. 154);

and indeed Wormeli acknowledges that teachers must maintain a modicum of mental health, advising that

> [f]or the sake of personal survival, you may choose not to allow any retakes or redos the last week of the marking period as you're closing down the grade book and doing report cards. For eight weeks, you're Mr. or Ms. Hopeful, but for that one week, it's OK to protect your sanity and personal life. You can allow students to learn the material and have their grade changed later. (p. 25)

2.2.2. Learning how to Learn

The rubric defines a set of criteria, and thus offers students more specific characteristics against which they can evaluate their own work - effectively providing a basis for the development of metacognitive skills (Flavell, 1979), and teaching students how to monitor and reflect on their own learning. Coupled with the understanding of what constitutes a good performance, metacognition drives students to “learn how to learn”, the basis for the development of 21st-century competency:

> The skills that you can learn when you’re at school ... will be obsolete by the time you get into the workplace and need them, except for one skill. The one really competitive skill is the skill of being able to learn. ... We need to produce people who know how to act when they’re faced with situations for which they were not specifically prepared. (Papert, 1998)

With a view towards teaching students to be lifelong learners, the effect of introducing criteria-based self and peer evaluations can be remarkable. In a controlled study, White and Frederiksen (1998) observed impressive effects for Year 7-9 students studying new units of work in science; and with particularly exceptional results for lower-achieving students, it offered strong indications that success criteria can

> enable students to see the intellectual purpose and properties of the [inquiry activity]. ... By reflecting on the attributes of each activity and its function in constructing scientific theories, students grow to understand the nature of inquiry and the habits of thought that are involved. (p. 13)

It should again be noted that the achievement of the students was quantified *in terms of the success criteria*. That is, students who were taught to recognise and apply success criteria, performed better against those same criteria:

> The Mass Projects were scored holistically on a 5-point scale for overall quality, as well as for each of the criteria for judging research shown in Figure 8 (White & Frederiksen, 1998, p. 32),

where Figure 8 referred to the "Criteria for Judging Research", a component that was presented to the treatment group students, but not to those in the control group.

The discussion around "learning how to learn" is obviously circular. What the White and Frederiksen study demonstrated was that this kind of learning, translated into a capacity to judge one's own performance against known success criteria, can be taught - just as students have traditionally been taught content; and the teaching of this skill has a significant impact on how well the student will achieve, when the achievement is viewed through the same lens.

Thus, in the White and Frederiksen study, the treatment students were taught values - the attributes of scientific inquiry that are important to the scientific community. As a consequence, this group of students knew what the teacher was looking for, when it came time to be assessed - and, while this can be thought of as "learning how to learn", it is yet the case that, for practical pedagogical purposes, it is not fundamentally separable from "learning how to perform".

2.2.3. Learning how to Perform

It is at this point that we must reconsider the effect of assessment on learning - and on learning how to learn. In practical terms, learning how to learn is a skill, acquired through experience in self- and peer-assessment, and as such may be cultivated by enforcing initial compliance, prior to scaffolding students to achieve deeper metacognitive understanding:

> Because many students have not learned to be self-motivated learners, such structure is necessary - at least initially. As students become independent learners, much more of the control should be given over to the students. (as quoted in Bolton & Elmore, 2013, p. 136)

This perspective on “learning how to learn” therefore lends credence to the idea that “learning how to perform” is an obligatory step in the process. According to this premise, the path to mastery requires guidance from successes and failures in performance. It should be noted that this “performance” describes an act that is fundamentally different to that captured by the performance goal / mastery goal dichotomy, which plays a significant role in fostering ego-related attributions (Wiliam, 2011, p. 110); and indeed the distinction between them is similar in nature to the varieties of motivation, as argued by Deci & Ryan’s (1985) Self-Determination Theory (SDT):

> SDT proposes that there are varied types of extrinsic motivation, some of which do, indeed, represent impoverished forms of motivation and some of which represent active, agentic states. (Ryan & Deci, 2000, p. 55)

To this, Wiliam (2011, p. 149) offers the following for clarification:

> If individuals undertake only those things that are inherently interesting or enjoyable, then they are unlikely to learn to read, write, or play a musical instrument. We are generally motivated to learn these things because we value the consequence, whether it is avoiding punishment such as that for not doing homework or reaching some external goal we have set for ourselves such as learning to drive or learning how to play a favourite song on the guitar.

While extrinsic motivation would not necessarily be required for all individuals, from a practical perspective, a teacher would expect to see variations in the motivations of the different students in a particular cohort. In such a situation, assessment - whether offered by a teacher or by the student's own developing sense of what is valuable - enhances learning by guiding the students towards mastery; and as such captures much of what is meant by formative assessment, or "assessment for learning".

2.3. Assessment in Secondary School Mathematics

The foregoing discussion touched on the complexities of secondary school learning and assessment, and with widely varying perspectives brought to this issue by different stakeholders, the practices employed to serve these ends can be highly contentious. As noted by Berry and Adamson's (2011) overview of this field,

> [a]ssessment has proved problematic and controversial because of its multivalent functions. The disparate goals of external accountability, competitive selection and diagnosis of strengths and weaknesses in learning are difficult to reconcile in a single assessment process. ... Assessment is therefore contested political terrain, encompassing a broad range of viewpoints, practices and values and characterized by power struggles, tensions and compromises. (p. 7)

The assessment of mathematics, in particular, is further complicated by certain properties of mathematics itself that are rarely shared by other secondary school subjects. Mathematics is unique in that complex thought processes can lead to simple, absolutely correct answers. It is a trivial matter to mark mathematics examinations if correct answers are the only goal. However, it is the terseness of the single correct answer that significantly complicates the assessment of an incorrect answer that might merit partial credit. Unlike human endeavours that can be quantified by an overall judgement of how closely it resembles competence, an incorrect mathematical solution must submit to a thorough analysis of just how the error (or errors) in reasoning occurred.

Therefore the assessment of mathematical competency lends itself to different interpretations, depending on whether the aim is correct answers or the development of mathematical thinking. Correct answers are undoubtedly worthwhile, but in their absence there are a multitude of alternatives; and indeed, in some cases, even a correct answer is insufficient if the student is unable to explain the process by which it was deduced (e.g. Yevdokimov, 2013). Indeed, with the perspective that "assessment is not really about numbers; it is about the structure of reasoning" (Mislevy et al., 2012, p. 60), the attainment of a correct answer may be considered to simply be a (possibly revealing) symptom of proficient reasoning.

2.3.1. Assessment and Streaming

In secondary school mathematics, there is usually a clear unidirectional link between assessment and streaming. Indeed, it appears that there is tacit agreement amongst all of the stakeholders in secondary school education, that it is reasonable to stream for mathematical ability. An overwhelming majority of parents, regardless of their children's ability levels, support ability grouping (Ansalone, 2010), and even some students see streaming "as necessary to preserve a sense of meritocracy" (Yonezawa & Jones, 2006). Principals recognise that the employment of this strategy makes their school more attractive to academically-oriented students (Ansalone, 2010), and teachers appreciate the reduction in the disparity between the achievement levels of students in the same class (Atkins & Ellsesser, 2003).

Of the many criticisms of ability grouping as a pedagogical strategy, it is perhaps its potential for perpetuating social injustices that is most persuasive for the purposes of instigating systemic change. The argument that students who are placed in "low" groups are doomed to learn in a comparatively more disruptive environment, means that ability grouping is "least advantageous for the very students who are most in need of a positive learning environment", and thus ability group assignment "becomes a self-fulfilling prophecy" (Eder, 1981, p. 160).

However, the nature of knowledge in the field can preclude the application of inclusive pedagogies to the teaching of mathematics. Mathematics is a pursuit in which knowledge and understanding is, in large part, hierarchical (e.g. Cahan & Linchevski, 1996): one cannot become an effective high-level participant without having achieved all of the intermediate steps. The attainment of mathematical understanding requires a solid grounding in what has gone before. Therefore, while it may be the case that mathematics teachers are accustomed to teaching in streamed settings, and in so doing internalise teaching practices that include ability grouping, it is unreasonable to attribute their preference for ability-grouped classes to their habitus within this field. The "considerable resistance to changing practice" (Zevenbergen, 2005, p. 610) is justified through reference to the potential seven-year disparity in mathematical achievement and understanding demonstrated by two students of similar chronological age (Siemon et al., 2001; Goss and Sonnemann, 2016); and the absurdity of de-streaming in some instances may be illustrated by suggesting that average Year 3 students and average Year 9 students should be grouped together for mathematics instruction.

The arguments in favour of homogeneous grouping for mathematics instruction fall into two broad categories. As a primary consideration, there is a view that students benefit academically from instruction that is adjusted to their pace of learning. Kulik and Kulik's (1992) meta-analysis on grouping programs found that, while ability grouping of itself had little effect on student achievement, significant benefits were observed when the curriculum was adjusted to suit the readiness of the students in each group. In the heterogeneous classroom, many teachers use the strategy of "teaching to the middle" (Rubin & Noguera, 2004, p. 95) and consequently some students are overwhelmed and frustrated, while others are bored by the lack of challenge.

Thus this need to cater to each student's unique learning needs gives rise to the second point in favour of homogeneous grouping: with a large range of abilities in the class, the act of teaching will inevitably become more complicated (Ansalone & Biafora, 2004). Ruthven (1987) found that a majority of mathematics teachers did not believe that the subject was suitable for mixed-ability grouping, as "differing rates of learning, powers of retention, and capacities for abstraction" (p. 244) contributed to the pedagogical complexity.

In sum, the factors that favour homogeneous grouping aim to match students with levels of instruction that are appropriate for their current cognitive development; and it appears that one reason teachers are reluctant to move towards heterogeneous grouping is that the act of delivering a highly differentiated mathematics lesson is non-trivial. However, even within a streamed setting, teachers must still consider this issue, as

> it has been shown that the range of ability and prior knowledge among a group of students who all score in the top three percentiles on a grade-appropriate test is as great as that found within a general population of students. (Mills, Ablard and Gustin, 1994, pp. 496 - 497)

2.3.2. Mobile Technologies and Assessment

In drawing upon the extant literature, varied viewpoints on the effects of mobile technological use in educational settings raise questions about educational quality and what the change seeks to achieve. While the vision of the potential for technology to transform teaching and learning is highly compelling (Traxler, 2009; Milrad et al., 2013), it is by no means clear that the results of that teaching and learning are necessarily improved. With reports of higher achievement through initiatives such as flipped learning (e.g. Pearson, 2013) contrasting with studies demonstrating a negative academic impact (Fried, 2008; Grace-Martin & Gay, 2001; Payne Carter et al., 2016), the uncertainty surrounding the effects of introducing technology into an educational setting highlights a need for examining the characteristics of different implementations.

That technology use in class has been found to correlate with lower academic achievement (e.g. Bowman et al., 2010; Fried, 2008) hints at a causal relationship, but if so the causes are not necessarily clear. As an example, Payne Carter et al. (2016) conducted a randomised trial for which technology was permitted in some classes and prohibited in others. A subsequent analysis of the students' final examination scores found that the classes with technology were significantly outperformed by those without. However, as noted by Payne Carter et al.,

> We want to be clear that we cannot relate our results to a class where the laptop or tablet is used deliberately in classroom instruction, as these exercises may boost a student's ability to retain the material. Rather, our results relate only to classes where students have the option to use computer devices to take notes. (p. 28)

In the Payne Carter et al. trial, the professors did not deliberately make use of the technology when it was present; they taught in the same way irrespective of the presence of technology, and therefore the technology did not play any role in the pedagogy.

In other instances, the use of technology whilst learning might see students develop a reliance on readily available external help – a form of distributed cognition (Pea, 1987) that may not be meaningfully evaluated in an artificially restricted technology environment. If "one cannot divorce assessment from content or how that content is taught" (Romberg, 1994, p. 7), then the assessment of mobile learning in secondary school mathematics must necessarily differ from commonly accepted, "traditional" methods of assessment, with its emphasis on the demonstration of skills performed in isolation and with limited technical assistance. Thus the direct adaptation of traditional mathematics assessment mechanisms for the evaluation of mobile learning is clearly flawed.

However, in the absence of an accepted, standardised evaluation technique for mobile learning, the available assessment mechanisms must form the basis for de-facto sufficiency. That is, despite the employment of mobile pedagogies in class, and students' learning being conducted within a technology-rich environment, it must be accepted that assessment techniques will regress to pre-mobile-learning forms. Indeed, as noted by Mislevy (1997),

> to further reject any use of these models and information-gathering tools just because they arose under the discarded epistemology is to forgo decades of experience about some ways to structure and communicate observations about students' learning … Believing these ways of structuring discourse hold no value is as wrong as believing that they alone hold value. (p. 197)

This situates mobile learning in secondary school mathematics in a transitional context, straddling both traditional and mobile pedagogies.

Therefore, it is currently expected that students would ultimately submit to being assessed using more traditional methods. It does not, however, necessarily follow that all assessments of the students' mathematical learning must be likewise limited. With a growing public awareness that students need to be assessed for 21st-century skills "like problem-solving and critical thinking and entrepreneurship and creativity" (Barack Obama, March 2009, as quoted in Darling-Hammond, 2014, p. 1), there is increasing acknowledgement that traditional assessment methods are insufficient for determining whether students have acquired skills that they will need for life beyond school.

2.3.3. The Changing Face of Mathematics Assessment

It is notable that, possibly due to the “difficulty of sound examining in mathematics” (Skemp, 1976, p. 12), mathematics assessment has diversified into a multitude of different streams, all of which are potentially defensible from different standpoints regarding the purpose of a mathematical education. From large scale external examinations seeking short answers, such as NAPLAN and the Common Core State Standards, to individual formative assessments between a teacher and a student, mathematics assessment spans a wide variety of methods and purposes.

One particularly noteworthy large-scale effort in mathematics assessment has been “Count Me In Too” (NSW Department of Education and Training, 2009), a professional development program aimed at Kindergarten to Year 6 teachers and their students. The purpose of the program was to support teachers to “better understand how children learn arithmetic”. It includes an assessment component which is “used by teachers to place each child at a point within [a learning] framework” and therefore combines elements of large-scale deployment with individual diagnosis and feedback.

The Count Me In Too program differs from much mathematics assessment in that it places students on a continuum of development, rather than scoring them for their attainment of a particular standard. It presents a kind of rubric for determining the level at which the student is currently operating, and offers indications regarding the next level towards which the student might aspire. It is therefore both formative in the sense that it is used as a diagnostic tool, and summative in the sense that it can also be used to categorise the students’ current level of mathematical attainment.

Examples such as these challenge the idea that objective assessment of mathematical attainment is only achievable under traditional examination conditions, and suggest that it is possible to reconcile alternative assessment methods in mathematics with defensible assessment outcomes. It is therefore of great interest to cases where innovative pedagogies are being introduced, since it demonstrates that it is possible to create alternative assessment methods that can objectively describe student attainment according to a different way of viewing mathematical understanding. With the potential for alternative assessment methods to challenge what is meant by mathematical achievement, a stronger case may be made for the pedagogies that these assessments tend to favour. The comparison between pedagogies can then be more fully informed by a more equitable comparison between demonstrable learning outcomes.

2.4. A Theoretical Framework

In considering the implications of mobile pedagogies for mathematics assessment, and vice versa, the present study is grounded in practical issues related to mathematics pedagogy. Influences upon both pedagogy and assessment in mathematics must be examined for their relative impact, as well as for their relative potential for determining the nature of change in this area.

It can be seen that the problem under study is relatable to Vygotskyan perspectives on learning (Vygotsky, 1978). In particular, Vygotsky's theories regarding an individual's Zone of Proximal Development (ZPD) consider an individual's current capabilities, and conceptualise effective teaching and learning opportunities for that individual as being those which slightly extend those capabilities. For the learning to be ambitious and yet attainable, should the appropriate scaffolding be made available, such educational endeavours would tend to encompass activities that are tailored to the student's current state of achievement.

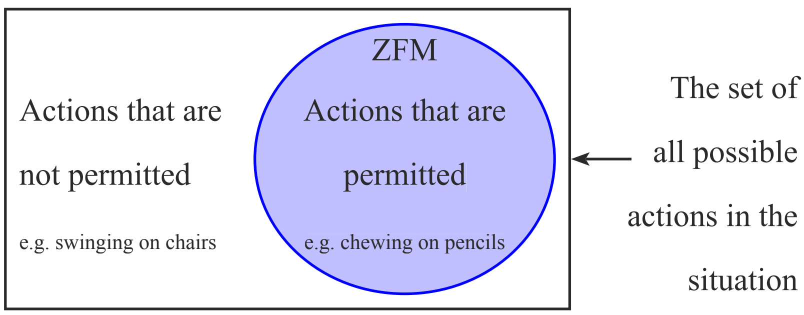
With mobile learning offering the potential for such scaffolding to be outsourced to technological tools (e.g. Kyza, 2009), Vygotskyan philosophies have expanded to encompass new and different notions of what it means to support an individual's learning. The development of mobile pedagogies that can enable learners to acquire more sophisticated modes of thinking and doing, and thus grow within their own Zones of Proximal Development, demonstrates the applicability of the Vygotskyan model to present-day pedagogical considerations. Indeed, the power of this theory lies in its ability to illustrate what is meant by effective teaching and learning, for an individual, at a particular stage in their development. In so doing, it offers a simple yet persuasive means of evaluating the merits of a proposed pedagogical modification.

Vygotsky’s ideas regarding what might constitute optimal learning for an individual are, however, insufficient for describing some other effects that may manifest with a change in pedagogy. Thus, to enlarge upon the concept of the ZPD, we shall turn to a theoretical framework described by Valsiner (1997) which incorporates the idea of the ZPD into a series of three “zones”, each of which represents different characteristics of the student’s learning environment.

2.4.1. Valsiner’s Zone Theory

In addition to Vygotsky’s Zone of Proximal Development, Valsiner offers abstractions of two further zones that each describe ways of classifying the actions taken in an educational context. The first such abstraction is the Zone of Free Movement (ZFM), which draws upon Lewin’s concept of free movement (Lewin, 1933 and Lewin, 1939, as quoted in Valsiner, 1997, p. 187) to describe questions of accessibility. The ZFM defines what may, or may not, be done in a situation, regulating both what objects and areas are accessible, and what actions may or may not be performed with these objects and within these areas. Since permission is a Boolean state, the ZFM also necessarily defines actions that are not permitted, and to maintain a particular ZFM, participants in the zone would need to be inhibited from straying outside the ZFM into actions that are not permitted. For example, a teacher might not permit students to swing on their chairs, but have an indifferent (and therefore permissive) attitude towards students chewing on their pencils (Figure 2.6).

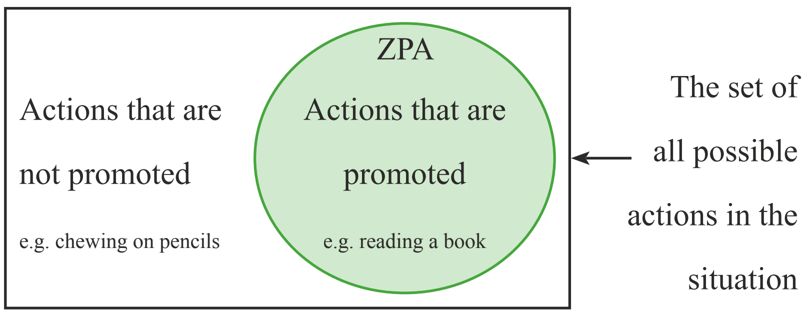
Figure 2.6. The Zone of Free Movement (ZFM) defines the actions that are permitted in a particular situation.



As a counter to the inhibitory nature of the ZFM, Valsiner introduced the concept of the Zone of Promoted Action (ZPA) (Figure 2.7) to classify those actions that are intended to promote the development of particular skills (Valsiner, 1997, p. 192):

> Parents may get involved in special efforts to promote their child's actions with an object that they consider important for the child's development … For example, during a session of "free play" of the parents and their toddler in the living room at home, the parents may try to get (and keep) the child interested in reading a children's book.

Figure 2.7. The Zone of Promoted Action (ZPA) defines the actions that are promoted in a particular situation.



Given these representations, it may be seen that Vygotsky's Zone of Proximal Development can likewise be represented as a diagrammatic "zone" - one that defines the set of actions that would be appropriate for extending the individual's personal capabilities.

In describing the zoniferous nature of the learner's environment, Valsiner took care to emphasise that a zone was not necessarily a continuously bounded area:

> Instead, it can include fuzzy or semipermeable boundaries, or an undefined boundary in many areas of the zone. The epistemological usefulness of the zone and boundary concepts lies in their flexibility in capturing the often partially fuzzy or indeterminate nature of the phenomena, rather than in adding stricter preciseness to a description of inherently imprecise reality. (p. 188)

Despite this, however, the convenience of visualising a “zone” as being not unlike a region on a Venn Diagram increases its usefulness for supporting simplified descriptions of these fuzzy and indeterminate phenomena. Thus, in discussions of mathematics and science teaching practices, Blanton, Westbrook and Carter (2005) were able to apply Valsiner’s zone theory to describe the relationships between the ZFM, ZPA and ZPD within the environments that teachers created for their students, and from thence to offer a diagrammatic representation that summarises these relationships in an elegant, albeit simplified, form (Figure 2.8).

The positioning of the zones in this manner is, on the surface, unsurprising. Having the ZPA wholly contained within the ZFM is logical; it ought not be sensible to promote an action that an individual is not free to perform. Likewise, it is reasonable to categorise students’ potential for development such that some portion of it is achievable within the teaching and learning situation, and some portion of it is not.

However, Blanton et al. (2005) and Goos (2005 and 2008) demonstrate that it is possible for the zones to be set out in different ways, and in so doing, their relative positioning can offer a lucid and eloquent articulation of the characteristics of a learner’s environment.

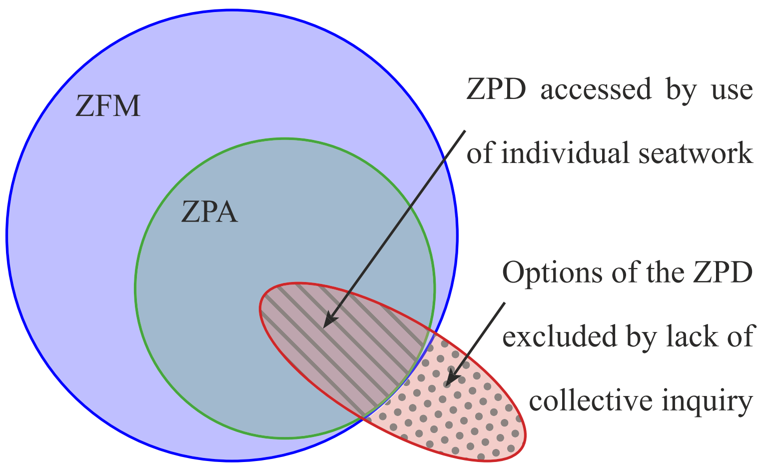


Figure 2.8. An interaction of the ZFM, ZPA and ZPD in a classroom context.

(Blanton et al., 2005)

For example, the relationships between these zones for a novice secondary mathematics teacher who was in the process of integrating computer and graphics calculator technologies into classroom practice, were described by Goos (2005) as shown in Figure 2.9.

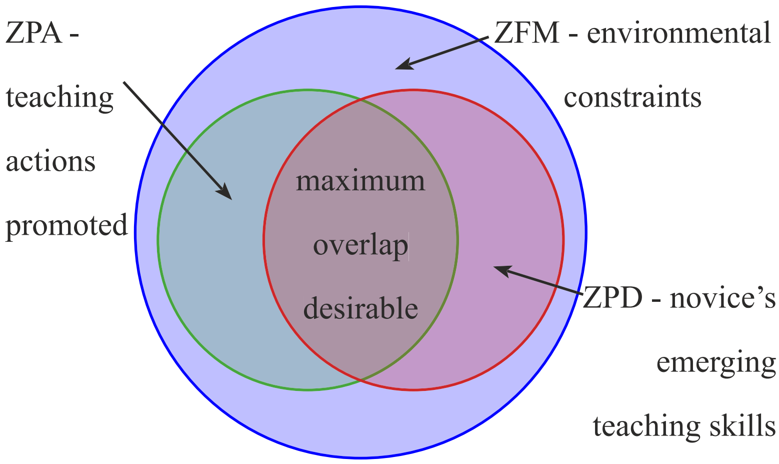


Figure 2.9. Relationships between the ZFM, ZPA and ZPD for novice teachers.

(Goos, 2005).

This representation demonstrates that the teacher had the freedom and latitude to implement the chosen pedagogy, subject to little more than environmental constraints. The aim, in this case, was an analysis of the teacher's developing ability to implement the desired teaching actions.

However, the configuration contrasts with Blanton et al.'s (2005) analysis of the ZFM/ZPA complexes organised by teachers within their classrooms. With the teachers in question implementing pedagogies centred around student-led inquiry, marked differences were noted in the relationships between the different zones. Not only were there ZFM actions that were not included in the ZPA, but indeed there were instances of ZPA actions that were not included in the ZFM (Figure 2.10).

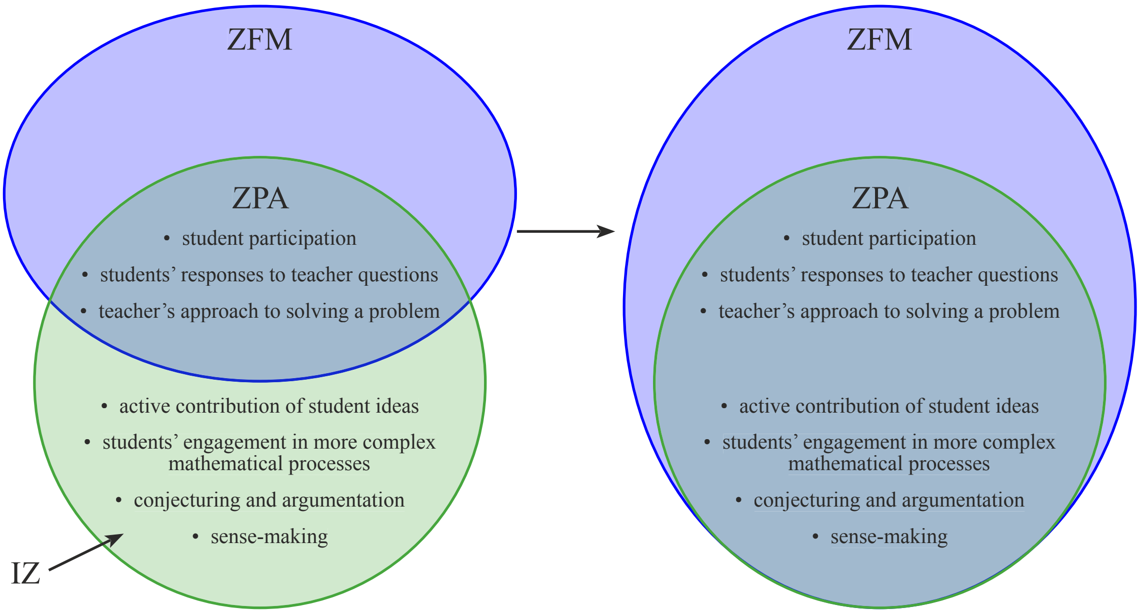


Figure 2.10. Changing relationships between ZFM, ZPA, and IZ due to changes in teacher practice. (Blanton et al., 2005)

> We describe this additional zone as the 'illusionary' zone of promoted action (IZ) and define it to be a zone of permissibility that the teacher appears to establish through behaviors and routines used in instruction, but in actuality, does not allow. We characterize this as an illusionary zone because it reflects an apparent contradiction in how the ZPA and ZFM interrelate. (Blanton et al., 2005, p. 14)

This idea of configuring the zones in different ways was also employed by Goos (2008) for describing the Teacher-as-Learner. Indeed, in noting that one of Blanton et al.'s teachers subsequently adapted their pedagogy to promote student interaction, Goos' diagram offers a base for representing the state of that teacher's practice (Figure 2.11). While the action (classroom discussion) was not initially included in the teaching and learning environment's ZFM, there was some evidence that it was present, in some form, in the teacher's ZPD - a circumstance that can be expressed in the zone diagram.

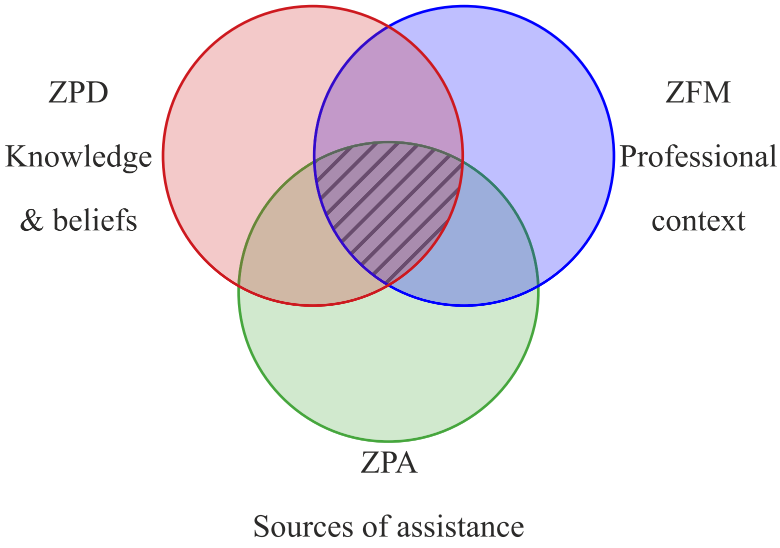


Figure 2.11. Using Goos' (2008) configuration to position classroom discussion for the Teacher-as-Learner described by Blanton et al. (2005).

Valsiner's zone theory offers a flexible and elegant framework for conceptualising the circumstances surrounding an individual's learning. It is particularly notable that the framework is as valid and useful for describing the acquisition of mathematical competence as it is for the development of mathematics pedagogy. Thus, as described by Goos (2008, 2010 and 2012), the zone theory has equal application for multiple perspectives in many different situations. These are not limited to those of Teacher-as-Teacher and Teacher-as Learner, but also have potential relevance for describing the development of Teacher-Educator-Researchers, and so on.

For this reason, I propose that Valsiner's Zone Theory would provide a suitable theoretical framework for the analysis of the results from this study. Since zone theory can be used to describe the constraints under which people operate in an educational context, irrespective of whether they are teachers or learners, it has the potential to offer an elegant way to conceptualise the teacher in both roles: both as a teacher of mathematics, where they are in a position to manipulate the zones, and as a learner of mobile pedagogies, where they would experience the constraints and suggestions that would be imposed on a learner.

3. Research Methodology

What we observe is not nature itself, but nature exposed to our method of questioning.

- Heisenberg

This chapter will describe the research methodology used. Given the size of the problem space, it was necessary to begin the investigation by clarifying the intent of the research questions; and to this end, consideration of research methods began with thought being given to a quantitative methodological approach, with concomitant arguments regarding both its suitability for answering the questions and the difficulties associated with implied statistical correlation. The resulting compromise situation proposed that it would not be useful for this study to access quantitative data directly, but noted that the influence of quantitative data could still be observed in teacher actions.

The chapter will continue with the choice to adopt a case study approach. With participating teachers drawn from seven different schools, a decision was made to consider the school, and not the teacher, as the case; this was despite the fact that some schools had one participating teacher and others had many. It made sense to categorise the cases in this fashion because many of the factors influencing the teachers' actions would have applied school-wide.

With seven case studies conducted within the subculture that is secondary mathematics education, consideration was also given to the potential for the study to be ethnographic in nature, particularly as it was possible to satisfy the requirement that the researcher be a participant in the culture. While the resulting methodology was a multiple case study, it was useful to consider approaches that would be used when conducting ethnographic research, and these approaches informed some of the choices that were made.

Following the methodological considerations, the chapter will then proceed with sections detailing the conditions for data collection, and an explanation of the reasoning behind the structure of the interview, observation and document analysis instruments. Finally, there will be some discussion regarding the potential for contamination during both data collection and analysis.

3.1. Research Questions Overview

The premise of this research is to explore mobile pedagogical adoption, but with a particular bent: it seeks to understand the relationship between mobile pedagogies and assessment. With one being a characteristic of the teaching, and the other representing a way of judging the effectiveness of the subsequent learning, this research represents, on the surface, an apparent confluence of ideas. There is an element of incontestability about this relationship; it is inevitable that such a link, between pedagogy and assessment, would be both obvious and unremarkable.

It is therefore necessary to define the nature of the question as being something of a moving feast. To elaborate, we shall first consider the questions that together comprise the conceptual purpose of this study:

1. What do secondary mathematics teachers value in student learning with mobile technologies;

2. How do traditional mathematics assessments influence teacher perceptions of the effectiveness of teaching with student-centred mobile technologies; and

3. What do mathematics teachers perceive to be the characteristics of assessment methods that enable and encourage the use of mobile technologies?

The questions being asked assume that pedagogy is currently in flux. The introduction of novel teaching strategies, such as mobile pedagogies, and the disruption that such pedagogical change might be expected to cause, is a given; it is accepted as being an ordinary state of affairs. It is expected that, given the ubiquity of mobile devices and the potential offered by improved technological capabilities, there will be teachers who will experiment with pedagogical change.

However, while it is perhaps self-evident that students who are exposed to the new pedagogical approaches will be assessed in the same way as those who are more traditionally taught, a comparison between these two teaching methods does not define the extent of the research. Rather, the purpose of the research is to explore bi-directional links between pedagogy and assessment; and since pedagogy is changing, it would be fair to assume that assessment may change also. The study is therefore positioned to observe innovative practice - outliers in both pedagogical choice and assessment construction; and, should one exist without the other, then that may highlight potential links between the old and the new.

3.1.1. Reconciliation of Opposing Methodological Viewpoints

To determine research methods for this study, we must first consider secondary mathematics teachers' decision-making processes when choosing to engage with mobile pedagogies. With particular reference to sociocultural theory and the idea that individuals and tools interact with, and transform, one another (e.g. Rogoff & Chavajay, 1995), the research aims to observe the influence of assessment practices upon the way mobile pedagogies are used. In addition, the study is also examining the converse view - it aims to ascertain what secondary mathematics teachers hope to achieve through their engagement with mobile pedagogies, with a particular focus on the effect of student-centred mobile technology use on mathematics assessment practices.

It may therefore be reasonable to expect that the study will examine the effect of mobile pedagogies upon summative assessment *outcomes*. Indeed, it may be argued that the present study will be incomplete if it does not include a quantitative analysis of summative assessment results, following engagement with various mobile pedagogical choices. With assessment and instruction considered to be “different sides of a single coin” (Harvey & Bright, 1991, p. 52), it would be difficult for a teacher to justify unilaterally making a pedagogical change without considering its effect on how well students are prepared for demonstrating their understanding in traditional assessments. Since today’s mathematics assessments almost invariably include examinations for which students are awarded marks, it would be expected that one of the factors being considered by a teacher in choosing a particular pedagogical approach, would be how well it will help the students to achieve as many marks as possible.

Given the nature of mathematics assessment regimes, the quantitative nature of this question is inescapable. As noted by Smith et al. (1996),

> Logistics and tradition have meant that assessment in mathematics has relied heavily on formal examinations. There are significant difficulties in changing this in early undergraduate years and little educational reason to do so.

With assessment in secondary school mathematics comprising, in large part, tasks that are classified by Smith et al. (1996) as “Group A”:

- Factual knowledge,
- Comprehension, and
- Routine use of procedures,

the objective grading of student responses is both simple and justifiable. Students are expected to produce short answers that are accurate and complete; and under these circumstances, there is very little in the way of “grey area” that may warrant a subjective assessment. The answers being sought are generally quantities, or abstract representations thereof; and production of the expected quantitative answers will generally earn quantitative marks - these being assigned according to a rubric that is extremely well defined, strict, and tight.

It is therefore incumbent upon the study to consider how teachers prepare their students to demonstrate achievement in an examination. Although the roots of this issue can be found in business and economic analysis more so than in education, it is evident that examination marks are a valued commodity that impacts upon pedagogical choice. If the problem were considered from a different perspective, then the usefulness of being able to ascribe improved measurable assessment results to a particular pedagogical choice is self-evident. Thus, a teaching method that correlates with demonstrable improvements in marks achieved in high stakes examinations, would likely be considered interesting indeed.

3.1.2. Considerations of Quantitative Methods

The choice of whether or not to apply statistical methods to quantitative assessment results must necessarily consider the meaning that may be inferred from such an analysis. It is perhaps ironic that, even though the subject matter deals in quantities, and the assessments grade the student responses quantitatively, it is not clear what meaning we can construe from these numbers.

Assessment through examination operates through the premise that mathematical achievement may be demonstrated on paper, under examination conditions. While examination-style assessments do tend to comprise the most heavily weighted component of high-stakes assessments in mathematics (e.g. NESA, 2017d; Cutler Ross, 1999; Senk et al., 1997; Smith et al., 1996), guidelines for fair testing from the Joint Committee on Testing Practices (2005) stress that there are limitations associated with test results, and that test users should “interpret test scores in conjunction with other information about individuals”. Indeed, assessment by examination is a method which, as argued by Skemp (1976), is insufficient for determining the presence, or extent, of student understanding.

Smith et al. (1996) illustrate this problem by noting the variation in understanding that may result in the production of the same answer on the examination paper:

> If a student is asked to prove a theorem given in lectures, a correct answer may be given by a student who understands the theorem and its significance and can apply it in relevant situations or prove similar theorems. However, the most we can assume is that the student can reproduce the theorem on demand; this style of assessment cannot discriminate between different types of learning which can lead to the same response. (p. 68)

However, the ability to produce such an answer would, in an examination, be considered sufficient for the awarding of full credit. Just as it is not possible to infer understanding from the student’s response, so it is not possible to infer the lack thereof. In such instances, the incentive is poorly placed; and if all that is valued is the student’s ability to write an appropriate response, then the examination is necessarily a relatively crude heuristic for determining competence.

It is therefore somewhat ironic that, although there is little that can be known about students’ mathematical understanding from the responses they offer in an examination, it is yet expected that the examination results offer a reflection of the students’ mathematical achievement that is good enough for the purposes of assessing their attainments within the context of school mathematics. The question of whether or not these assessments are sufficient for this purpose is largely irrelevant, because the system traditionally assesses in this way; it is close to being a fixed feature of the landscape in which mathematics teachers operate.

Thus, it appears reasonable to analyse pedagogical approaches for their quantitatively measurable effects on current assessment outcomes - a perspective that is borne out by the myriad studies that focus upon this particular aspect of the relationship between pedagogy and assessment. For example, Rohrer and Taylor (2007) described a series of experiments that examined the effect of "mixed" mathematics practice, a pedagogical approach that differs from the usual method of having students practise series of problems that were all amenable to very similar methods of solution - a grouping strategy that was referred to as being "blocked" by problem type. The quantitative results demonstrated that the "blocked" practice students exhibited better performance during the practice sessions, but the "mixed" practice students had the advantage when working under test conditions, as shown in Figure 3.1.

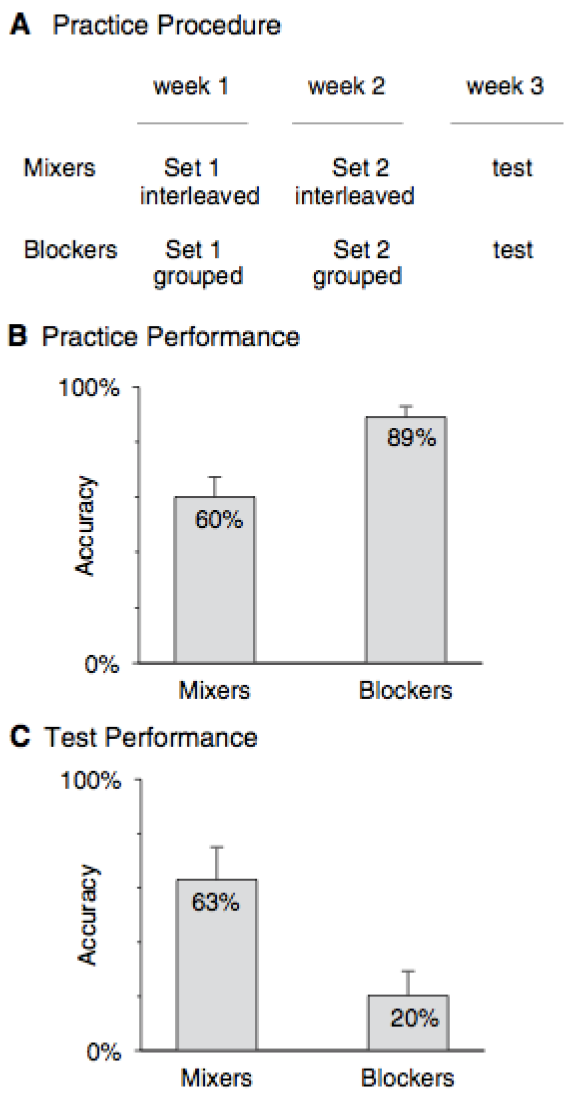


Figure 3.1. Image from Rohrer and Taylor (2007), p. 493.

Similar quantitative testaments to pedagogical efficacy for the purposes of improving assessment results can be seen in studies that range from Bangert-Drowns et al.'s (1991) meta-analysis of frequent classroom testing, to Balota et al.'s (2007) review of spacing effects.

The existence of such quantitative demonstrations of the superiority of various pedagogical approaches does not, however, indicate that improvements in assessment results are unequivocally representative of superior pedagogy. As an aim of the education system, improved examination results are problematic because they imply a great deal of faith in the assessment mechanism. This is a construct which is subject to compromises, and which may be influenced by any number of factors unrelated to mathematical achievement - including such disparate considerations as politics, expediency, and purpose (Berry and Adamson, 2011). With assessments varying to cater for arbitrary bureaucratic requirements, such as ease of marking or the need for students to be assessed for either competence or relative ranking, it is by no means clear that improved outcomes for one purpose are meaningful for any other.

The difficulty of ascribing better examination outcomes to better teaching is particularly well illustrated by the improvements that were ostensibly obtained within large scale assessment regimes such as NAPLAN, which has been run Australia-wide since 2008. While results in this test have demonstrated improvement since its inception, the same gains are not evident in more recent years. As noted by the Australian Curriculum, Assessment and Reporting Authority's chief executive in 2016,

> When we look to last year there's not the sustained effort that we would like to be seeing on a year-to-year basis, so we're a bit concerned it's levelling off, that's not what anyone wants to see. (as quoted by Dalzell, 2016, para.3)

The trend towards plateauing results mirrors the results from other large scale assessments such as the National Assessment of Educational Progress (NAEP), which was used to measure the success of the original No Child Left Behind law in the USA (Guisbond et al., 2012). In both cases, while it is impossible to prove the reasons for the declining rate of change, there are indications that the demonstrable improvements during the first years of the test may have been due to teachers gaining an appreciation of what it was that the test valued.

It is therefore arguable whether such a measure is meaningful. If better results were due to teachers internalising what was needed for performance in the test, then it is by no means clear that the celebrated improvements were due to better teaching. Indeed, as noted by Smith et al. (1996), all it shows is that the students had acquired a superior facility for demonstrating the knowledge that was expected by the test.

3.1.3. Characteristics of the Examination as an Assessment Mechanism

The foregoing discussion regarding the implications of quantitative data and its associated considerations, gives rise to questions regarding how the research would be positioned with respect to assessment. As a study which purports to investigate links between pedagogy and assessment, the present concern must consider the outcomes of the assessments - this being a factor that, if untreated, would be obvious by omission, leaving a great void in an area that is necessarily central to the entire question. Since the purpose of an assessment must include the production of an outcome, whether formally or not, it behoves the present study to consider assessment outcomes as a component in the overall scheme. Thus, not only do assessment outcomes need to be considered, but they must be foundational. For the purposes of research into assessment, assessment outcomes must be a consideration that is both essential and interesting.

As a commonly employed assessment mechanism in secondary school mathematics, examinations lend themselves very well towards quantitative analysis, and indeed may be considered by all interested parties - students, teachers, parents, and other stakeholders - to offer an objective and unbiased assessment of student learning. Traditional examinations are a well-understood construct with well-understood constraints, and there is a general perception that they promote a high level of fidelity in the assessment process.

Therefore, despite concerns regarding the kind of learning that mathematics examinations might value, or how quality in teaching may or may not be accurately reflected in examination results, for the purposes of discussing links between pedagogy and assessment, the examination must be considered as an assessment method of particular interest. If we accept that this is the case, then it necessarily follows that the outcomes from examinations are also of interest to this study.

How, then, can the study explore this dimension of the problem, without reference to quantitative analysis of examination results?

3.1.4. The Adoption of a Case Study Approach

In order to obtain a more complete picture of the relationship between pedagogy and assessment, without reference to any quantitative data, the study seeks to place itself in the teacher's position. From this perspective, it is apparent that mathematics teachers act upon a number of stimuli - potentially including, but not limited to, examination results, and the wish to have their students assess well in an examination (e.g. King-Sears & Baker, 2014). In viewing examination results through the lens of a teacher, the data are transformed from raw numbers into something far more subjective - teachers' thoughts and perceptions, and teachers' actions.

It is for this reason that I chose to adopt a case study approach. With a view towards discussing mathematics pedagogy and assessment, this approach sits comfortably within a conservatively qualitative and somewhat post-positivist paradigm (Guba and Lincoln, 2005) - neither denying the influence of the quantitative, nor relying on it for proof.

To further clarify what is meant by a case study approach, I shall borrow from Stake's (2005) terminology regarding the different types of case study - intrinsic, instrumental, and collective - to be defined as follows:

> Intrinsic - if the study is undertaken because one wants better understanding of this particular case;
>
> Instrumental - if a case is examined mainly to provide insight into an issue or to redraw a generalisation; and
>
> Collective - an instrumental study extended to several cases.

Since the present research does not focus on any one particular case, but instead seeks to examine a number of cases in detail in order to gain multiple perspectives into teaching and assessment methods, it aligns most clearly with Stake's characterisation of the "collective" case study approach.

With a limited number of cases, the present study is not as far-ranging as a traditional ethnography, although Denzin's (1997, p.xiii) observation that "it is no longer possible to take for granted what is meant by ethnography" appears to require a response in this regard. Therefore at this point it would be useful to clarify what is, and is not, included in my understanding of what the research entails, beginning with Denzin's characterisation of the role of the ethnographer:

> The ethnographer discovers the multiple “truths” that operate in the social world - the stories people tell one another about the things that matter to them. These stories move people to action, and they rest on a distinction between fact and truth. Truth and fact are socially constructed, and people build stories around the meanings of facts. Ethnographers collect and tell these multiple versions of the truth. (Denzin, 1997, p.xv).

Ethnography can therefore be considered as a form of storytelling. It paints rich, complex pictures of social interactions and social constructs; it interprets, and offers insights into, behaviours that arise from participation in a culture. As members of a well-defined society, secondary mathematics teachers operate within a culture that is subject to the aforementioned “multiple truths”; and, through their shared experience, the parameters and characteristics of this culture are well understood. While the story of any one teacher may offer different representations of facts and truth, the situation would still be recognisable to other teachers, thus potentially offering insights with which the observer can sympathise.

With this perspective, the present study may be characterised as having some ethnographic links; and as discussed by White, Drew and Hay (2009), semantic arguments regarding what is meant by “ethnography” suggest that there is often little difference in intention between ethnography and case study research. Indeed, the practical advantages of the case study have often made it the method of choice for ethnographic research, even though it may result in findings that have less generalisability (Abercrombie et al., 2000, p. 47).

3.2. Structure of the Study

3.2.1. The Case Study Approach

Since the primary concern of the research is to learn from teachers and their actions, methods were required that would allow exploration and description of the complexities inherent in teachers' decision making. The study seeks to deconstruct the interaction between pedagogy and assessment, as it is seen through the eyes of a teacher. With a particular focus on mobile pedagogies, its charter is to learn from teachers' experience with mobile pedagogies, the teachers' views regarding assessment, and the ways in which these two constructs interact.

To this end, the study comprises a series of case studies, which individually offer vignettes of teacher practice. The scenes were chosen for their ability to illustrate interesting practices - teacher thoughts and actions that together offered an appreciation of the rationale behind the use of mobile pedagogies, and the connections the teachers drew between the pedagogical choices and their assessment practices.

The case study approach is particularly applicable for the present research because it offers real teacher interpretations of the practice under scrutiny. It is in the implementation, as opposed to the theory, that we can appreciate the "uncertain, complex, messy and fleeting properties" of educational contexts (Freebody, 2003, p. 84), allowing the description of findings that are translatable to practice. Thus the necessarily situated nature of the findings does not render them useless for the purposes of transfer; rather, it demonstrates an appreciation that teachers are constantly adapting their practice to the demands of the subject matter and the characteristics of the students, a process which is informed by past exposure to teaching situations that might be similar, but never identical.

For the present research, each case study consists of a narrative description of the practices within a school. I chose to name the school, and not the teacher, as the case, even though four of the case studies focused on a particular teacher and the other three had multiple teachers in the one school; this was because a lot of the data was relevant school-wide. For example, assessment tasks were used across each year level, and not just in one class; and aspects of school culture, student characteristics, socioeconomic status, and so on, would apply across the school. To avoid confusion, case studies with only one teacher participant are described in such a way that it is clear that there was only one teacher involved.

With the school as the case, pedagogy and assessment can be discussed in a holistic sense, since characteristics of lessons and assessment tasks are likely to be more representative when considered in combination. While it may be possible to infer some of the teacher's pedagogical preferences from the observation of a single lesson, it is clear that such a picture is likely to be incomplete, being overly influenced by the occurrences of the day, and any particular pressures that might be present during that period in the school calendar.

To illuminate each case study, information was obtained from three different angles: the teachers' opinions, their actions, and their choices for evaluating student learning. The aim was to combine data from each so that the entire analysis may draw upon multiple sources. Thus, in order to more fully experience the teacher's world, a combination of data collection methods was employed, each of which was suited to understanding a particular component of the teacher's practice. In isolation, each of these methods would have been insufficient, being liable to contradiction from another quarter; but in combination, it was expected that the picture they paint would be rich, extensive, and complex.

3.2.2. Participant Recruitment

A particular advantage of an ethnographic approach in this situation was that it could focus on a sub-culture of interest. Freebody's (2003) discussion of approaches to the ways in which participants may be selected for study argues the rationality of choosing to take a non-random sample; and thus, since the present study seeks to gain insights into links between mobile pedagogies and assessment, teachers who (for example) did not engage with mobile pedagogies were not expected to offer insights that would be interesting for this purpose.

For this reason, a "purposeful selection" approach was adopted:

> These people are selected because they are taken to represent instances of best cases or worst cases (e.g. according to some external criterion such as test scores), … typical cases (e.g. beginning teachers with 'average' university grades) or special interest (e.g. experienced teachers of severely intellectually impaired students). (Freebody, 2003, p. 81)

In the case of this research, teachers were selected for their adoption and familiarity with mobile pedagogies - that is, pedagogies that are suitable for teaching and learning with personal (i.e. student-centred) mobile technologies. With an aim of observing pedagogical practice with mobile technology and the associated assessment mechanisms, the selection criteria for participants focused mainly on just one criterion - the use of student-centred mobile technology in class. Since the study seeks to explore the teachers' beliefs and actions, the ways in which the mobile technologies were used was not a consideration when seeking interest from potential participants. With a deliberate focus on teacher perceptions, it was considered that pre-judgements regarding the nature and sophistication of their use of mobile pedagogies might skew the research too much in favour of the researcher's own pedagogical agenda; and indeed, it was hoped that there would be some divergence in the ways in which the different teachers had developed pedagogical practices that would take advantage of student-centred mobile technologies.

Thus, several different approaches were used to make initial contact with the case study schools. In particular, the study deliberately sought access to schools that were diverse in characteristics, such as entry criteria, educational philosophy, sources of funding (government, independent or Catholic Diocesan), and socioeconomic status; and so approaches were made to a variety of schools with attributes that were not currently represented in the study. As an example, one such characteristic was the academic selection of students, and in this case the school that was approached, kindly agreed to participate. With the final group of seven schools, the research was able to discuss findings more generally, in the understanding that the schools were all very different and indeed did not demonstrate a bias towards any single attribute.

Of the resulting case study schools, two were purposefully chosen participants in the aforementioned ARC Discovery Project (see page 6). In addition to the two Project schools, I obtained permission to observe five other secondary schools (Table 3.1). For three of these schools, initial contact was made with a particular teacher, rather than the school itself; this was due to the author's familiarity with the teachers in question, and an appreciation that their pedagogical practices were likely to be both well-considered and diverse.

One further teacher was recruited through advertisement. He responded to a call for volunteers, which was kindly broadcast by the principal supervisor of this thesis.

The final teacher was recruited through recommendation. The school, in this case, was representative of some unique qualities, which were believed to be singularly influential

Table 3.1. Case Study Schools.

School	School Type	Recruitment Method
Bermondsey College (Philip)	Independent Girls NSW	Personal contact
Chesham House (Patrick)	Independent Co-Educational NSW	Advertisement
Elm Park High School (Daniel)	Government Academically selective NSW	School Recommendation
Farringdon High School (Holly and Will)	Government Comprehensive Co-Ed. NSW	Personal contact
Moorgate Secondary College (Multiple teachers)	Government Comprehensive Co-Ed. Victoria	ARC Discovery Project
Osterley High School (Elizabeth)	Government Partially selective NSW	Personal contact
St Johns Wood Catholic College (Multiple teachers)	Catholic Co-Educational, Yrs 7-10 NSW	ARC Discovery Project

in pedagogical choice; and thus particular efforts were made to obtain permission to observe this distinctive sub-culture.

School names and teacher names were changed for reasons of confidentiality.

3.2.3. Ethics and Informed Consent

The data collection phase of this research was preceded by an application to the UTS Human Research Ethics Committee (HREC). The approval letter is included in Appendix A-1.

The ethics process produced a number of documents and letters which were provided for each teacher who participated in this study. Copies of these letters and documents are included in Appendix A-2.

Ethics considerations for the Project schools were handled by the project team, with the aim of providing a fairly broad scope for data collection. In particular, the Project sought to interview students as well as teachers, and thus obtained permissions beyond what was considered to be necessary for the present study.

For each of the non-Project schools, the first data collection activity comprised an interview with the participating teacher, and permissions were sought from each teacher at this initial interview.

Since the study seeks to investigate teachers' pedagogical choices, there were few if any potential risks to the participants in the research. Indeed, with an aim of observing the teachers' methods because it was believed that there was much to be learned from their practice, there was little scope for the participants to experience ill effects; the participants themselves had chosen to be involved as a consequence of their expertise in the field.

3.2.4. Questions of Access

With respect to access issues, the schools participating in the present study can be divided into three distinct groups: Project schools, NSW Independent, and NSW Government (refer "Table 3.1. Case Study Schools." on page 70).

Access to observe within the Project schools was handled by the project team, and the present study did not take part in these negotiations.

With respect to the schools that were not involved in the Project, I had little difficulty with obtaining access to observe lessons after a relationship was established with a teacher within the school. Teachers who had agreed to participate in the study readily acceded to requests for lesson observations. In the case of independent schools, letters were then sent to the principals to seek permission to observe the teacher’s classes, and both of the independent schools were forthcoming in this regard. An example of the letter and information sheet for the principal is attached in Appendix A-3.

In the case of government schools, after agreement was received from the teachers, approval was sought from the NSW State Education Research Applications Process (SERAP). The subsequent approval letter was then posted to each government school, along with an information letter, similar to that sent to the principals of the independent schools (see Appendix A-4 for the SERAP approval document).

3.2.5. Conditions for Data Collection

With three distinct data collection methods, the study sought to consider each teacher's convenience and thus data collection was performed in a variety of ways and in a number of different locations.

3.2.5.1. Interviews

All interviews were conducted at each teacher's convenience. They were scheduled to suit each teacher's timetable, with a duration and in a location of their choosing. Thus, durations for interviews varied widely, ranging from 30 minutes to two hours; and locations included school offices and conference rooms, cafés and restaurants.

3.2.5.2. Observations

Observations of teaching practice were scheduled at each teacher's suggestion. Thus, teachers would nominate a date on which they would like observations to be conducted. With an aim of exploring innovative practice, this arrangement suited the intent of the research, since it was expected that teachers would not always be doing something that was particularly novel, and would not necessarily want all of their lessons to be observed. Indeed, after giving the teachers free choice with respect to the observation schedule, it was found that different teachers chose their observation dates according to different criteria, with some selecting dates on which "normal" classes would be held, while others would deliberately schedule interesting activities for the observation.

During each observation, the teacher introduced the researcher by name and stated to the class that the lesson was just going to be observed. It was not uncommon, however, for students to interact directly with the researcher; for example,

> Are you the sub today, miss? (Student, Chesham House)

and thus conversations between the researcher and the students would often occur. Indeed, in some classrooms, the students would actively seek assistance from the researcher regarding the mathematics with which they were currently engaged, and in all cases the teacher approved the researcher's involvement before such interactions went ahead.

3.2.5.3. Document Analysis

Requests for assessment tasks for document analysis were made in the course of each interview, and again this was not prescriptive - teachers sent tasks that they felt might be of interest. Thus, while it was generally the case that the assessment tasks in question were related to the work being done during the observation, teachers also suggested other assessment tasks that they felt might be relevant to the research.

3.3. Semi-Structured Interviews

As noted by Taber (2013, p. 274),

> Interviews are often an especially useful way to explore how people experience situations, how they understand concepts, and what they think about things.

As a data collection mechanism, the interview is one of the more versatile instruments, since it allows the researcher to target particular issues through dialogue with the participants in the study (Stake, 2005, p. 453). Since it is interactive, answers to questions of interest may be actively sought, not just passively observed, thus permitting the researcher to explore phenomena that are not made manifest in any other way.

Within the context of this study, the interview was the method of choice for elucidating teachers' thoughts. It offered a means through which the teacher could provide the reasoning behind different pedagogical choices.

There was, however, a subtler reason for employing this method of data collection. The interview was the only method that was reasonably available to this study, that could hope to access certain types of historical information. Of all of the potential influences upon teachers' practice, one of the more significant must be the teacher's experience; and while it may be possible to infer a level of experience when observing a teacher's practice, such inferences must necessarily be of a general nature. Any appreciation of contributing factors, including the teacher's background and any incidents in their life that may offer explanations for particular choices, would not be readily available for a researcher whose role was only to observe.

Thus, a semi-structured interview format was chosen, which included a limited number of guided questions, and which offered enough freedom for teachers to just talk about their practice. The aim was to give the teachers an opportunity to carry through any trains of thought that were relevant to the overarching questions at hand. Interviews were audio-recorded and subsequently transcribed.

3.3.1. Interview Questions

The following section describes the construction of the interview questions, with rationale given for choices regarding the wording and placement of each question. Since the interviews were intended to be semi-structured, it was considered important to phrase the questions in such a way that the teacher did not feel constrained with respect to the scope of their response. I also constructed a printed prompt to support the respondent in describing the relative importance of different skills that may be important for demonstrating mathematical achievement.

3.3.1.1. Setting the Scene

The questions in the interview were constructed to begin with a small number of procedural responses (Figure 3.2). Although this was done mainly for the purposes of broad classification, the choice to have them up front was deliberate - the positioning was strategic, with consideration having been given to the pros and cons of having them at the beginning, rather than at the end of the interview.

> **Semi-structured Interview Questions**
>
> - For how long have you been teaching (secondary school maths)?
> - For how long have you been using mobile technologies in your teaching?
> - What year levels do you teach?

Figure 3.2. Semi-Structured Interview Questions, Part 1.

The reason that these questions came first was partly to allow the teacher to feel comfortable in the interview setting. It was expected that, at the beginning of an interview, questions with easy and ready answers would be less confronting than an in-depth discussion of pedagogical choices.

However, a second reason that was equally important for the purposes of this study was that the teacher would have the opportunity to volunteer information that was relevant for the study - information which could potentially be prompted by these apparently procedural questions. While the question regarding the number of years spent teaching may have limited scope for expansion, the second question could, for example, possibly cause the teacher to ask what was meant by “using mobile technologies”. Was it teacher-centred or student-centred use? Would it include using the device as a textbook, or would it mean using it for demonstration, explication, collaboration, research?

The question was posed in this way in the hope that it would facilitate this interaction. At this stage of the interview, it was important for the teacher to know that the interview was intended to be dialogic - that they were able to ask questions too; and in asking these questions, it would become possible for the researcher to roughly gauge the amount of thought that the teacher had put in to the issue, of what it meant to employ mobile pedagogies. As an example, it may be inferred that a teacher who qualified their response with the years spent using mobile devices as a textbook, and the years spent using mobile pedagogies for student-led constructivist learning, would have had to have considered this difference in advance. Therefore, the implications of volunteering this distinction, rather than having to be prompted for it, could be that the teacher's practice might have been more reflective, and their pedagogical choices more deliberate.

The question regarding year levels was also designed to be slightly leading. It was expected that, even if the teacher did not volunteer extra information for their experience with using mobile pedagogies, they would likely expand upon a question regarding the classes they teach. Thus, without asking the question, it was expected that a teacher would naturally qualify a statement regarding teaching Year 8, with a distinction of which Year 8 class it actually was. A response stating that "I teach the bottom class in Year 8" would, for example, offer an opportunity for the researcher to ask the teacher about the school's streaming practices.

Indeed, the inference would be equally valid for an unqualified response. Should a teacher respond with "This year I'm teaching Year 7, Year 8, Year 10 and Year 11," then the same window of opportunity would be present, in which it would be natural for the researcher to request clarification of the kinds of classes they were. Indeed, the lack of streaming practices could potentially be more remarkable than their presence (e.g. Zevenbergen, 2005), and could offer some considerable insight into the culture of the school.

3.3.1.2. Links Between Assessment and Learning Design

The second set of questions focused on the ways in which the teacher thought about pedagogy and assessment in combination (Figure 3.3). It sought to explore a particular assessment instrument in detail, in order to understand the teacher's perceptions of its purpose and its validity - whether or not it was a reasonable means by which to judge the quality of a student's learning.

> Please show me an assessment instrument that you would use with one of your classes after they engage with mobile learning.
>
> For each assessment instrument:
>
> - What kind of work (including but not limited to mobile learning) would students be doing in the lead-up to this assessment?
> - Do you design the assessment before, at the same time as, or after designing the learning activities?

Figure 3.3. Semi-Structured Interview Questions, Part 2.

Given the nature of these questions, it was impossible to predict the subsequent discussion. Indeed, prior knowledge of any intricacies of the assessment would not have been relevant for the purposes of elucidating the teacher's thoughts. It was expected that, if the teacher had particular views regarding characteristics of the assessment instrument, it would be preferable for the teacher to believe that the researcher was unfamiliar with the instrument, and thus have cause to explain their observations in greater detail.

The first sub-question, therefore, referred to the teacher's pedagogical choices. It was hoped that the phrasing of the question implied a consideration of the assessment when the pedagogical choices were made, so that it would be possible to determine whether the assessment was influential in those choices. With an aim of gaining a picture of the mixture of teaching methods employed in the lead-up to an assessment, it was hoped that the question would provide the teacher with an opportunity to describe not only the learning activities, but the effect that planning for assessment would have on their teaching. Again, although the expectation was that the teacher would respond in an expansive manner, even a simple listing of teaching and learning activities would provide material that would allow the researcher to prompt for further detail.

The question regarding whether it was the assessment or the learning activities that were designed first, was included because it was a detail that would be less likely to be foremost in a teacher's mind, and thus may be missed in this discussion. This consideration of the order of operations would perhaps have been less important if the assessment format had been conventional; for example, while the teacher may not have either written or seen the actual examination paper, their internalisation of what an examination paper looks like, and the styles of question that might be expected, would have been sufficient to guide their pedagogical choices.

However, if the assessment was a recent innovation for the school, then the order in which it was conceived was highly relevant. If the assessment came first, then it was possible that it was an idea of valued learning, that could have driven a particular method of teaching - a purpose towards which teaching could be aimed. If the assessment came after the conception of the learning activity, then it was the learning activity that was driving the teaching and learning process, and the assessment was then invented to determine whether or not that learning activity had been successful.

3.3.1.3. Student Assessment Outcomes

For each assessment instrument (cont.):

- What do you hope the students will demonstrate in this assessment?
- Why do you value this learning?
- What would good student work look like?
- What would not-so-good student work look like?

Figure 3.4. Semi-Structured Interview Questions, Part 3.

In order for the teacher to evaluate the effectiveness of a newly conceived set of learning activities and the related assessment task, it was expected that the teacher would have formed some ideas of how the assessment would be able to show what the students had learned (Figure 3.4). Thus the associated question, regarding what the teacher hoped the students would demonstrate in this assessment, was intended to probe aspects of assessment design. While the question may have been of little value for summative examinations where the only outcome of value was the number of marks achieved, it was hoped that, for more innovative assessment methods, it would prompt for some perspectives regarding the kind of learning that the teacher hoped the assessment would allow the students to demonstrate. As an example, it may have been the case that an assessment instrument was designed for multiple points of entry and exit, and the expectation for each student would vary depending on their aptitude, interest and engagement. It may alternatively have been the case that the assessment was designed for multiple methods of solution, and if so it was possible that the students would demonstrate the employment of their own judgement, and the ways of thinking that worked well for them.

The question regarding why this learning was valuable, was expected to elicit thoughts regarding what the teacher considered to be the purpose of teaching and learning; and as such it admitted of a multitude of perspectives. The responses in this case were expected to vary from preparedness for high-stakes examinations, to the importance of creativity or ingenuity in mathematical thinking, to issues of equality of educational access; there were, of course, as many possible responses as there were valued outcomes. Should the teachers' values encompass a number of different areas, then there would be scope for discussing the relative merits of these values, and the weight that would be given to each, under different circumstances.

Considerations of student submissions followed, and if the teachers had not yet done so, it was at this point that they could produce examples to illustrate the aspects of student learning that they considered to be valuable. While it was expected that innovative assessment methods would lend themselves well towards a discussion of particularly memorable student submissions, this was a question that should also have relevance for teachers who only assessed through traditional examinations. In such cases, as an example, ingenious solution methods could potentially be contrasted against the uncovering of student misconceptions. Indeed, it is perhaps the case that, even though the examination marking rubric may be unable to distinguish between students who actually do understand the mathematics, and those whose understanding is incomplete, the teachers themselves would be able to make more subjective judgements regarding the quality of the students' work, and be more capable of appreciating the differences in mathematical achievement:

> It is easy to have mistaken assumptions about the skills that a particular task assesses. If a student is asked to prove a theorem given in lectures, a correct answer may be given by a student who understands the theorem and its significance and can apply it in relevant situations or prove similar theorems. However, the most we can assume is that the student can reproduce the theorem on demand; this style of assessment cannot discriminate between different types of learning which can lead to the same response. (Smith et al., 1996)

3.3.1.4. The Impact of Mobile Learning for Assessment Performance

Following a discussion of the learning and assessment that would occur under this teacher's guidance, insights were requested into how well this arrangement prepared students for the assessments to which all students must submit. That is, if there was a known point towards which all students were expected to aspire, then did the teacher believe that their method was effective for guiding the students in that direction?

Questions regarding the nature of the learning were expected to challenge the teacher to explain the reasoning behind the pedagogy - to see how they justified what they were doing, with particular reference to the necessity of preparing students for high-stakes examinations (Figure 3.5). It was not intended to be particularly leading, in the sense that the teacher could well admit that a good deal of the learning was unrelated to anything that would be valued under examination conditions; but as a pedagogical consideration, the appreciation that the learning was not examinable must be at least as relevant as noting how the teaching was

- Do you expect this learning to change how students perform in other assessments (e.g. end of year exams, NAPLAN, etc)
- How is student learning changed by engaging with the mobile learning? (How is this evident in the assessment submissions?)
- How do you think student learning is affected by the assessment?
- Do the results from this assessment contribute to any final grades or ranking of students?
- Would you teach in this way if the students were going to be assessed by sitting a traditional exam over which you had no influence?

Figure 3.5. Semi-Structured Interview Questions, Part 4.

directly relatable to assessable skills. In contrast to direct instruction, an indirect approach to teaching and learning would admit of a wider range of perspectives regarding how students acquired mathematical knowledge and understanding, and a discussion of the teacher's appraisal of the pros and cons of different pedagogical approaches would shed some light on their choice of teaching method.

3.3.1.5. Future Directions for Mathematics Assessment

- What (if anything) would you like to change about mathematics exams?
- What (if anything) would you like to change about mathematics assessment?

Figure 3.6. Semi-Structured Interview Questions, Part 5.

Following a discussion of the assessments that were used within the school, a picture would have emerged which included the more intangible qualities of the circumstances under which the teacher worked. There was therefore sufficient background at this point to allow the researcher to understand the cultural assumptions within the school, regarding what was considered to be valuable learning, and what was considered to be worthwhile assessment.

With this appreciation of the teacher's situation, it became possible to discuss potential changes to assessment practices, without requiring a great deal of clarification regarding how the proposed regime would differ from the status quo. It was at this point, therefore, that teachers could expound upon their own ideas for how assessment should be, and offer thoughts regarding the reasons why these assessment methods were not currently in use.

3.3.1.6. Valued Learning

The final part of the interview structure was intended to allow the teacher to discuss what they considered to be valued learning, and the circumstances under which the learning was valued. The rationale for this part of the interview was to deconstruct the teacher's practice with respect to assessment. If we consider the potency of the assessment instrument in communicating to the students the learning that is actually valued - as noted previously,

> Students are often more motivated to learn material or methods that are of direct relevance to passing (Smith et al., 1996, p. 66),

then what the teacher considered to be valued learning must be significant for appreciating the characteristics of the assessment method of choice. Thus, if the teacher valued performance in high-stakes examinations, then the ways they assessed student learning may have demonstrably valued the skills required to do well in examinations - and indeed, to reinforce this point, the assessments may have resembled examinations as they would be set by external authorities. If the teacher valued 21st-century competencies, then they might have reified this stance by constructing assessments that required students to demonstrate 21st-century skills, and so on; and, indeed, if the teacher valued 21st-century competencies but did not communicate these values to the students, then their valuing of these competencies would have had little effect upon the student experience.

To this end, while the interview continued as before, the proceedings were facilitated through a printed prompt, which was formatted in a manner not unlike a survey (Figure 3.7). The teacher was asked to rank a number of characteristics for their importance for different assessments, in order to draw out their discussion of how their own teaching practice valued skills that were useful for examination performance, and skills that were important for life after school. The purpose of this was to inform any subsequent analysis of the

Please rank the demonstration of these skills in order of importance (1 most important; 5 unimportant) for:	Mathematics exams	Your summative assessment tasks	Your formative assessment tasks	21^{st} century mathematics education
Problem solving: Closed problems (1 correct answer)				
Problem solving: Open problems				
Problem solving: Authentic problems				
Communicating: Deciphering questions				
Communicating: Seeking clarification / information				
Communicating: Explaining				
Reasoning				
Understanding (knowing both what to do and why)				
Fluency: Speed of calculation				
Fluency: Memory (for mathematical facts, formulae)				
Matching problems with learned procedures				
Work ethic				
Accuracy of solution				
Estimation of solution				
Ability to follow instructions				
Being organised / tidy / careful				
Collaboration				
Creativity				

Figure 3.7. Interview Prompt in tabular format.

ways in which the teacher employed mobile pedagogies. That is, how did the teacher's values relate to their pedagogical choices?

Despite its appearance, Figure 3.7 was not a survey instrument, and was never intended as such. The purpose of the format was to provide a means for the teachers to describe relative weightings; its aim was to create a language for "very important" and "very unimportant" that was precise enough to convey, for any one characteristic, the teacher's perception of just how important the demonstration of that characteristic might be, under different circumstances.

Thus, the aim of the instrument was to facilitate discussion rather than to gather statistical evidence. Indeed, since there were no plans to analyse the results as though they were statistically interesting, an efficient method of representation was deemed the most appropriate, irrespective of how it might compare with other data collection instruments. This was, indeed, just a means of expressing an open-ended interview question, with the aim of eliciting, amongst other things, a considered opinion - one which may be more clearly expressed through reference to its neighbours, and the relative darkness of their particular shades of grey.

To this end, a numerical scale was chosen over a Likert-style format for reasons of clarity and expediency. It was expected that, given the profession of the interviewee, a tabular format with numerical responses would be both comprehensible and elegant; and although this was not an expected outcome, it was thought that the nature and granularity of the scale would neither confuse the respondent, nor be an impediment to expression. Mathematics teachers were unlikely to have difficulty understanding the relative weightings of "1" and "2", or to have trouble expressing a rating of "2½", or indeed "3¼", if they so chose. Furthermore, it was hoped that the brevity of the numerical response might prompt the teacher to clarify the meaning of their response, or indeed to clarify the meaning of the question that was being asked.

In reference to the latter consideration, it must be noted that the table as shown in Figure 3.7 includes a modification that occurred during the first interview in which the table was used. This modification was a direct result of clarifying the intent of the question being posed. The original table had only three columns for responses:

- Mathematics exams,
- Your assessment tasks, and
- 21st century mathematics education.

During the first interview, it became apparent that "Your assessment tasks" was insufficient; there could, of course, be summative assessments which were not examinations, which were set by the school and potentially by the teacher being interviewed; and as well as this, there were certainly formative assessments that the teacher would have carried out in the classroom on an on-going basis. Since this omission was discovered early, the effect of this realisation was to change the table at the outset, and thus the table as shown is representative of what was used in all cases.

The choice to specify skills for discussion was made after consideration of the potential for particular areas of interest to be forgotten during the interview process. The construction of this list borrowed heavily from "Working Mathematically", a central component of the NSW syllabus (Board of Studies, 2012; also see ACARA, n.d.b, and VCAA, n.d.), as well as 21st century skills associated with learning (Trilling and Fadel, 2009, p. 49) that were not already represented in Working Mathematically. These sources were chosen because they offered language that would be well understood by NSW mathematics teachers for the purposes of discussing mathematics pedagogy.

However, despite the use of accepted terminology for the skills that were valued in mathematics learning, there were areas in which the commonly used terms were insufficiently clear; and where this occurred, the skills were divided into multiple parts. For example, as a valued skill, "Problem Solving" would be a concept that could be interpreted in a number of ways, ranging from the ability to solve closed problems through to the ability to manage a mathematical investigation - and, indeed, it is clear that any discussion of the skill of problem solving must be qualified with the nature of the problem to be solved. Thus, with such disparity between multiple skills that go by the same name, it was necessary to include sub-categories of "Problem Solving" so that all facets of the skill could be covered. The clarifications that were necessary for specifying these sub-categories were, however, worded as vaguely and non-specifically as possible, so that the teacher would be able to interpret the question through reference to their own practice.

As well as Working Mathematically concepts, there were a number of characteristics that, while not specified as being central to mathematics education, are nevertheless present in many mathematics teaching and learning situations. Matching problems with learned procedures, work ethic, accuracy and estimation, following instructions, and being organised, tidy and careful, are characteristics that exist within a somewhat nebulous "hidden curriculum" - one which is poorly specified, but potentially both highly valued and well understood.

3.3.2. The Hidden Curriculum of Working Mathematically

Although Working Mathematically is central to the mathematics syllabus documents, its definition is fuzzy and its components are inevitably open to interpretation. Thus there are aspects of mathematics teaching that do not obviously belong in any one category or another; and while some of these skills are never canvassed or described in the curriculum, there is an expectation that they are nevertheless necessary for mathematical achievement.

As an example, the skill of matching problems with learned procedures may be considered to be a variety of "fluency" - that is, fluency of procedure. However, I would suggest that this skill crosses over all of the different aspects of Working Mathematically, as it also sees students communicate (interpret a problem), problem solve (produce a response to the problem), reason (apply logical thinking) and understand (appreciate that what they are doing actually makes sense). Thus it is difficult to classify this skill as any one or another of the Working Mathematically skills. Being able to identify an appropriate procedure to use under the right circumstances is clearly advantageous for the purposes of demonstrating mathematical achievement, and as such it can form a part of the teacher's pedagogical repertoire - particularly when what is valued is the demonstration of aptitude.

Another facet of school mathematics that is often central to the way in which it is taught, is its reliance on practice to develop students' skills. As an example, it can be seen that the current focus on "Growth Mindset" (Dweck, 2015) and persistence in the face of difficulty tends to favour the development of a certain work ethic. Students are expected to take on challenges, risk making mistakes, and persevere when things go wrong - in short, they are expected to work hard, and to assume that worthwhile learning will not be easy to acquire. Thus the question regarding work ethic was aimed at eliciting the teacher's thoughts regarding the importance of this facet of mathematics pedagogy.

3.3.3. Further Considerations for Assessment Practice

It is perhaps curious that, in the mathematics syllabus documents (NESA, n.d. and VCAA, n.d.b), there is little, if any, mention of some aspects of mathematics pedagogy that are highly valued in mathematics assessment. This is particularly the case when we consider the importance of accuracy for performance in mathematics examinations. Although it may be due to a perceived redundancy in identifying it as a requirement, it is nevertheless the case that the syllabus does not specifically discuss the importance of correctness in mathematical responses.

As a foil to a focus on accuracy, the ability to estimate a likely answer is potentially useful, particularly in real-life situations. Thus, while mathematics examinations tend to value accuracy, there is potential for arguing that the skill of estimation - that of being able to deduce quickly whether a result is in fact in the right ball park, and therefore makes sense - is a skill that is becoming more highly valued in today's world:

> In most cases, a computerised tool does the actual calculation, but using the model without understanding the mathematics leaves one vulnerable to potentially serious misjudgements (OECD, 2012b, p. 31).

The teacher's perception of the relative importance of accuracy and estimation was therefore potentially significant for an appreciation of the outcomes that they value. It was hoped that the question was sufficiently neutral; all attempts were made to avoid associating a value judgement with the skill, so that there was no implication that (for example) accuracy would be for exams, and estimation for real life. The teacher had the freedom to rate the importance of the skill for either situation, in any way they chose.

Other skills that might be associated with assessment, more so than the mathematics curriculum, were skills that would be required for demonstrating the acquisition of learning, under examination conditions. These included an ability to understand and follow explicit instructions, given in both verbal and written forms. Although Working Mathematically in the NSW syllabus includes “Communicating”, the implication is that this refers to higher-order skills such as making sense of word problems and being able to explain mathematical thinking; and while the ability to follow instructions is certainly a communication skill, the skill is a basic one, with relatively low expectations for cognitive load. However, this skill was included as a potential discussion point because it appeared to be one without which students would be unable to demonstrate competence in traditional assessments.

Yet another skill that was potentially important for demonstration of competence was the skill of being organised, tidy, and careful. The employment of a mobile device could mean, for example, that there was no need to write legibly - despite its being a skill that may be necessary for communication under examination conditions. It was therefore considered interesting to note the importance accorded to this skill, when the teacher made pedagogical choices.

3.3.4. Further Considerations for Mobile Learning

With reference to the pedagogies of particular interest to the present study, consideration must be given to the characteristics of the learning that it was intended to promote. As with other hidden curricula, this learning is difficult to specify as being deliberately and intentionally required. So while Working Mathematically is central to the NSW syllabus, an emphasis on (say) higher-order thinking skills is not mandated for mathematics teaching and learning; and since the valuing of higher-order thinking skills is not explicitly imposed on the teacher, its presence in the teaching would indicate that the teacher appreciates its importance.

As an example, collaboration is a skill that is generally considered to be promoted by mobile learning. One of the great strengths of mobile learning is that students can communicate with their peers, and learn to work with others in constructive and rich interactions (e.g. Kearney et al., 2012; Dillenbourg et al., 2009); however, as a skill, collaboration would tend not to be tested under examination conditions. It was, therefore, interesting to see if, and how, collaboration was valued in the teacher's practice, and if their pedagogical choices favoured the development of this skill.

Likewise, mobile learning offers considerable support for creative ways of working, allowing students to access a rich fund of materials for open-ended problem solving, and providing a medium through which they can demonstrate their thinking in a multitude of ways. Thus it was interesting to note the teacher's consideration of how important creativity really was, and if they did consider it to be important, how they conveyed this perspective to their students.

3.4. Observations

As the original and most basic form of ethnographic research, participant observation is a method that is particularly useful for gaining an appreciation of the setting in which the teaching and learning occurs. Wilson's (1977) seminal review of ethnographic techniques discusses the influence of the setting on human interactions, where

> forces generated both by the physical arrangements of the settings and by internalised notions in people's minds about what is expected and allowed (p. 247)

prompt a realisation that the setting is fundamental to understanding the phenomenon being researched.

The appreciation that such forces exist therefore leads to the conclusion that human research is best conducted in naturalistic settings; and in the case of schools,

> if one wants ultimately to generalise research findings to schools, then the research is best conducted within school settings where all these forces are intact. (Wilson, 1977, p. 248)

For each of the case studies, observations formed the second point of reference for analysing the teachers' practice. The rationale for observing the teachers in action was to gain an appreciation for the context in which they conducted their lessons, and how their ideas for developing students' abilities were translated and implemented in their classroom. The purpose was therefore to understand what elements of the theory actually worked in practice.

A single observation shall be defined as being a single lesson; that is, the students and the teacher interacted in a particular location for a set period of time. The duration of the observation was thus defined by the arrival and departure of the participants in that group. All observations were conducted in class situations in which students used mobile devices.

The unpredictable nature of classroom interactions necessarily meant that observations would only offer snapshots of practice that may never again occur in quite the same way. Thus it is important to emphasise that the observation was not intended as a critique of the teacher's practice; it was not an assessment of the effectiveness of the pedagogy, or of the teacher's competence in delivering the lesson. Rather, it was intended as a fuller explanation of the constraints under which the teacher operates; a demonstration of just one of the infinite variety of ways in which the lesson could proceed; and an opportunity to clarify intentions which may be discussed in a subsequent debrief. Its ultimate purpose was therefore to provide the "picture" that gives life to the "thousand words" from the interview.

3.4.1. The Role of the Researcher

In conducting observations, it is inevitable that the presence of the researcher changes the dynamic within the interactions being observed (Taber, 2013, p. 270). Not only is the researcher necessarily an outsider, but an obvious one, being an adult where the only other adult present is the class teacher.

Therefore, to avoid contaminating the classroom interaction as far as possible, the researcher was introduced to the students at the beginning of the class, as being an associate of the teacher who was just going to observe the lesson. It was expected that students would be familiar with Education students on practicum, and other similar visitors to their class; and it was hoped that this familiarity would be sufficient for rendering the researcher essentially uninteresting, and potentially invisible.

Thus the researcher would adopt an unobtrusive position, and as far as possible would not interact with either the teacher or the students, for the duration of the observation. Also, while written notes were taken, there was no need to document the proceedings using photography or audio recording equipment; although exceptions to this rule occurred for the Project schools, for which the project team had obtained permission to interact with students, and to document observations through photography.

3.4.2. Observations: The Setting

The first point of interest for the observation was its location. Ordinarily, it was expected that an observation would occur in a classroom, in which case the characteristics of the classroom may include:

- the arrangement of furniture;
- the positions of the whiteboard(s), whether interactive or otherwise;
- any decorations, such as motivational or mathematics-related posters.

The setting would include an indication of the time at which the lesson was conducted:

- time of day (e.g. second period, or first period after lunch);
- day of week;
- time of year (e.g. two weeks before the yearly exams)

as well as a broad classification of the students in the class: year group, number of students, gender differences, age differences, and any students with special needs - such as students with a disability, or English language learners.

Students' actions upon entering this space were noted, with potential for difference in modes of entry (silent, social, or disruptive); seat selection; and the production of mobile devices, books, and writing equipment. The observation schedule included such details because I wanted to see if the mobile devices were accepted, everyday tools for use in class. If students produced devices immediately upon entry, that would be different to students keeping the devices in their bags and producing them when the teacher asked them to do so; and again different to students having devices in their hands when they entered, and putting them away before the lesson began. Questions regarding discipline, such as seat selection, were also considered to have potential relevance.

3.4.3. Observations: The Lesson

It was expected that the researcher's prior familiarity with the content of the lesson would vary from one observation to another. For example, it was possible that the teacher would have described the intended lesson to the researcher in the lead-up to the observation; likewise, it was possible that the researcher would have preconceived notions regarding how the content might be taught, or alternatively be completely unfamiliar with the topic. The observer therefore adopted a neutral stance with regard to the lesson content and presentation, and accepted the teacher's delivery at face value.

In particular, the lesson observation sought to be sensitive to the dialogic interaction between the teacher and the students. While all attempts were made to observe the lesson impartially, the observation also benefited from the adoption of a particular stance - either that of the teacher, or that of the student. A third lens, from the perspective of "a fly on the wall", was also useful for describing some aspects of the interaction.

Questions that were used to guide the observation included considerations of lesson planning, mobile device usage, student actions, and any assessments that were carried out during that lesson. The observation schedule, included in Appendix A-5, was based largely on my own experience following observations at the two Project schools, where I followed schedules set by experienced researchers. It was created after they guided me through this apprenticeship, and it built upon elements that I had picked up while watching other people work.

3.4.4. Observations: The Debrief

Following the lesson observation, there was a time for discussion with the teacher regarding their perceptions of how the lesson went. If it was not possible to have the debrief on the same day, then a subsequent interview was scheduled, so that the teacher could discuss their impressions and talk about any thoughts that occurred to them in the course of that period.

During the debrief, the teacher was also asked to discuss ways in which the learning from that period would be expected to be assessed - either formatively or summatively. Any assessments that were conducted during the lesson would also be discussed. Questions regarding assessment use during the lesson are included in Appendix A-6.

3.5. Document Analysis

As a third angle from which to observe a teacher's practice, assessment tasks set for students at the case study schools would also offer insights into the ways in which teachers chose to assess student learning. Indeed, it may be argued that the document that specifies the assessment task - whether it be an examination paper, or the requirements for a student project - could potentially be the most critical communication from the teacher to the student, regarding what was valued in student learning. It would offer a written, and almost contractual, specification of what it was that the teacher wanted the students to achieve.

As a prepared document, the assessment task specification might potentially be amenable to a variety of quantitative analysis. Riffe, Lacy and Fico's (2014) discussion of communication analysis describes such quantitative methods, arguing that

> the only way to logically assess communication content is through quantitative content analysis … Only this information-gathering technique enables us to illuminate patterns in communication reliably and validly. And only through the reliable and valid illumination of such patterns can we hope to illuminate content causes or predict content effects. (p. xiii)

With quantitative content analysis (QCA) being used to "verify or confirm hypothesized relationships" (Altheide, 1987, p. 68), it was clear that this approach would not be appropriate for the purposes of the present study. With a focus on innovative practice, there was essentially no hypothesised relationship to begin with; and indeed, in this case, a statistical analysis was unlikely to offer particularly meaningful insights, or to allow valid inferences to be made. With only a limited number of case studies, the assessment tasks being analysed were necessarily few, and required consideration in the context of what the research was aiming to achieve. Thus, the purpose of the analysis was not to find patterns in assessment construction; rather, it was to flesh out the picture of a single teacher's practice. It was intended to illuminate one facet of the teacher's practice, so that the teacher's choices may be more completely understood.

The necessarily qualitative nature of this document analysis allowed it to maintain close ties to the case study approach. A focus on reflexive analysis situated the interpretations within each case study, so that the documents could be understood in context. Thus, instead of being driven by a predetermined protocol, the analysis was continually fine-tuned to accommodate the qualities of the documents being studied, and the characteristics of the case study with which they were associated:

> Although categories and "variables" initially guide the study, others are allowed and expected to emerge throughout the study. Thus, ECA [Ethnographic Content Analysis] is embedded in *constant discovery* and *constant comparison* of relevant situations, settings, styles, images, meanings and nuances … To this end, ECA draws on and collects numerical and narrative data, rather than forcing the latter into predefined categories of the former as is done in QCA. (Altheide, 1987, p. 68, italics in original)

3.5.1. Document Sampling

The nature of assessment in this study was, of necessity, very loosely defined. With an exploratory view of innovative practice, what would be considered to be "assessment" for the purposes of this study had to encompass all actions that resulted in a communication of student achievement. Thus the assessments being analysed may, or may not, have been marked and graded; they may, or may not, have contributed to summative judgement; they may or may not have been conducted under examination conditions; and so on.

The nature of the present study - being both exploratory, and focused on innovative practice - roughly defined the set of assessments that could usefully be analysed. Since case study schools were specifically chosen, and teachers chosen for their innovative practice, then it was clear that an exploration of assessment practice that did not inform these cases, would not be relevant for the purposes of this research. Thus the current study did not seek saturation coverage of assessment tasks; nor did it even seek to analyse a representative sample of all of the assessment tasks that were set by the case study schools. Rather, the focus was on obtaining samples of assessment practice that either exhibited innovative characteristics in and of themselves; or alternatively, to obtain assessment documents that, while not necessarily outliers in assessment practice, were nevertheless used to ascertain the level of student achievement following the employment of mobile pedagogies.

3.5.2. Document Analysis

As just one component of a more complete picture given by each case study, each assessment task was considered in light of the context in which it is offered. Since, as noted by Romberg (1994), “in practice, one cannot divorce assessment from content or how that content is taught”, it was clear that the assessment tasks would not stand on their own, and their characteristics would have no meaning, unless considered alongside the pedagogical choices made by the teacher.

Thus the analysis of each assessment task was necessarily conducted within the case study in which it occurred. Its purpose was to offer a third perspective from which the teacher’s practice could be understood. Each assessment task was therefore considered in relation to the teaching and learning that preceded it, and the consequences which followed, both for the student and for the teacher. It was a fixed mark on the journey between the act of teaching, and the effect that the teaching had had.

For the purposes of this research, each case study was essentially a narrative which was populated by pedagogy and assessment - two components of teachers' practice that fed reflexively upon each other. This meant that assessment discussion would necessarily be interspersed with pedagogical discussion, and it was expected that in combination, common effects might be explored. It was also, however, expected that themes would be identified for assessment instruments that shared common characteristics.

Thus, while the assessments would need to be considered together with the pedagogy to be fully understood, assessments that shared common features could also be examined as a group, so that their associated pedagogical approaches might be compared. Likewise, when two cases exhibited similarities in pedagogical considerations, then their respective assessment mechanisms could be compared and contrasted. Indeed, it was expected that such comparisons could offer insights not only into commonality of practice, but also to inform a discussion of whether some characteristics of each assessment instrument were in fact non-essential for the purpose of ascertaining student achievement in such a case.

Assessment analysis and classification was therefore expected to be a multi-dimensional exercise. A matching of assessment with pedagogy would be succeeded by a consideration of the pedagogical characteristics of the different cases, as well as an appraisal of commonality and divergence in pedagogical approach with respect to the characteristics of the assessment method.

3.6. Reflections Regarding Impartiality

Since the present study was conducted by a researcher who is qualified to teach secondary school mathematics, it is necessary to consider the effect of the researcher's background upon all aspects of the research methodology. In particular, it was expected that the researcher's "insider" status would influence the interactions with the participating teachers.

3.6.1. The Insider/Outsider Status of the Researcher

As discussed by Corbin Dwyer and Buckle (2009), there are significant issues with being a member of the population being studied. Since it would be disingenuous for the researcher to ignore any common understandings that were shared with the participants, it was important to make the researcher's background clear to all, and thus all of the teachers were aware that the researcher had once taught secondary mathematics. As well as this, there were some instances in which the researcher also had other characteristics in common with the participating teacher - for example, common gender or ethnicity, being a parent, shared experiences at university, or having taught in, or indeed attended, very similar secondary schools.

As an example, there was one case study to which the researcher had particularly privileged access. A mutual acquaintance aided the researcher in obtaining access to observe within the academically selective government school, Elm Park; and when introductions were made, staff at Elm Park were informed that the researcher was an alumnus of another academically selective government school. While it is not known whether this influenced the school's decision to engage with the research, during the course of the interview, the participating teacher (Daniel) also admitted to having attended an academically selective government school himself, and referred familiarly to the practices at these schools throughout the interview.

It was, therefore, expected that any characteristics of the researcher that were known to the participating teacher would potentially affect the nature of the interview. This was particularly the case when the sharing of experience would sometimes occur. Even though there was an understanding that the researcher should be impartial, the conversational style of a semi-structured interview meant that it could not always be guarded, and dialogue would inevitably take place in which the researcher's own experience would inform the discussion. Indeed, it could not be otherwise; nuances in wording, and in the phrasing of a question, must demonstrate biases from prior experience, whether intentionally or otherwise. When a respondent requested clarification, the explanations and examples given must necessarily draw upon the researcher's own repertoire.

The difficulty of conducting consistently impersonal interviews is described in Corbin Dwyer's (2009) account of her research with White parents of Asian children. As a member of this population, Corbin Dwyer discusses her discovery that, during data analysis,

> I realized I sometimes shared experiences, opinions, and perspectives with my participants, and at other times I did not. It is not that I sometimes saw myself as an outsider instead of an insider. Rather, not all populations are homogeneous, so differences are to be expected. (p. 56)

Varying degrees of "insider" status meant that similar interactions would exhibit different characteristics for different case studies. The ability of the researcher to relate to a particular teaching and learning situation would inevitably vary according to the differences between the case study school and the researcher's own experience, and this could potentially affect the nature and depth of the questions being explored.

In an attempt to view these interactions from the teacher's perspective, it was also evident that, if the researcher could view herself as more or less of an insider in a particular situation, it was likely that each participating teacher also conducted a similar categorisation of the researcher. The bi-directional nature of this judgement would likely magnify any resulting effects, so that there was a potential for observations to vary considerably in the ways that situations were perceived. It was felt, for example, that should the researcher and the participating teacher recognise that there was little commonality of experience, then observations that were almost from the perspective of an "outsider" could theoretically occur. When, on the other hand, the educational context was very similar to one that had been present as a formative experience in the researcher's past life, lack of distance was certainly an ever present danger.

External considerations that might inform the teacher's practice were also often discussed, particularly when familiarity and a certain rapport developed between the researcher and the participating teacher. Thus, some teachers would talk of their home life - their spouse and children, particularly if the children were of school age. Discussions of teaching practice were thus occasionally informed by considerations of how the teachers' own children learned, and the teaching methods that were employed at other schools. One teacher discussed the effect of his career on his home life, and the consternation of his wife when he spent long hours at work instead of with his children. Another, in describing the importance of the role that parents played in their children's education, offered a student work sample that had been created by his own daughter, in order to illustrate the effect of having a parent who was sufficiently familiar with educational expectations. While such personal admissions were not specifically prompted through the interview questions, it was clear that the teachers felt that these experiences were relevant to their practice, and meaningful for explaining the rationale behind the pedagogical choices being made.

In reviewing the transcripts from the interviews, there was a sense that some of the opinions being expressed were quite frank, especially with respect to difficult students or controversial policy. It may therefore be inferred that, when this occurred, the participating teacher viewed the researcher as having sympathy with their perspectives. Indeed, it was certainly the case that, being a fellow secondary mathematics teacher, the researcher had often experienced similar situations first-hand, and would not have viewed the participating teacher's opinions, motivations, or actions, in a judgemental way. Nevertheless, an awareness that this sympathy exists offered a position from which the research may consider its effects. As Becker (1967) notes, sociological research engenders

> self-doubt for those who do the research, who would like to be sure that whatever sympathies they feel are not professionally unseemly and will not, in any case, seriously flaw their work. (p. 239)

Like Delamont's (2002) description of Miss Ximenes (p. 35), the research required an appreciation that the views of the teacher should neither be ignored nor accepted uncritically. By giving voice to such opinions, the teacher was offering a view of the influences upon their practice; and despite a collegial appreciation of their perspectives, the research demands an unsentimental exploration of these views.

3.6.2. The Roles of the Researcher

Delamont (2002), in discussing the pitfalls of fieldwork, describes the effect of "going native" - meaning

> over-identifying with the respondents, and losing the researcher's twin perspectives of her own culture and, more importantly, of her "research" outlook. (p. 37)

She makes the point that, in living the experience of the participants in the study, there is the potential for ignoring other angles from which a situation might be observed. Indeed, it is notable that the present study only considered the teacher's point of view, and essentially ignored the perspectives of students, parents, policy makers, the wider community, and any other categorisations that might be made of potential stakeholders in this scenario.

Within the wider context of ethnographic research, the issue of "going native" is a common concern. Becker (1967) describes the problem of "taking sides" with the rhetorical question,

> Will the research, we wonder, be distorted by that sympathy? Will it be of use in the construction of scientific theory or in the application of scientific knowledge to the practical problems of society? Or will the bias introduced by taking sides spoil it for those uses? (p. 239)

He makes the point that, due to our sympathies with the respondents,

> we might distort our findings … by misusing the tools and techniques of our discipline. We might introduce loaded questions into a questionnaire, or act in some way in a field situation such that people would be constrained to tell us only the kind of thing we are already in sympathy with. (p. 246)

The present study is not immune to accusations of bias in this regard. There was, of course, the potential for questions to be phrased in such a way that the respondent would answer in an expected fashion. The researcher was also able to interpret the data selectively, perhaps imposing a layer of meaning, or ignoring unexpected answers in order to focus on the researcher's own agenda.

Indeed, it would be well at this point to consider the researcher's own background, and any biases that may be introduced by virtue of her situation. With a previous career in computer science, including a particular focus on computational mathematics, coupled with a teaching career that has focused largely on students who have experienced academic success, it is evident that the researcher's own outlook has been coloured by an underlying assumption that existing mathematics assessment regimes are fair and reasonable, and that mathematics pedagogy does not necessarily benefit from the affordances of mobile devices. Thus, while there is a recognition that such assumptions are flawed, it would be logical to assume that the researcher embodies a set of biases that need to be consciously overcome; and so it is possible that attitudes detrimental to any proposed changes to pedagogy, or to assessment regime, would manifest on an unconscious level.

Any interpretations of the data that would be made by a researcher who, in effect, wears different hats at different times, must therefore be viewed in light of the whole story. While the lens through which the data were examined was necessarily flawed, the underlying post-positivist paradigm proposes that a truer image would result from piecing together data gathered from multiple perspectives. This triangulation of methods offers a means of enhancing internal reliability (Freebody, 2003, p. 81); a particularly important consideration with a case study approach, where the deconstruction of each scenario into its component elements would likely result in misleading interpretations. With just seven in-depth case studies, there were not enough participants to dilute any biases that may be manifest in this way. For this reason, each case study must be presented in its entirety.

It must also be accepted that, by virtue of the way in which the research question was defined, the study was obviously and deliberately biased. By defining the population by selection, biased sampling was introduced even before any fieldwork had occurred. Thus any suggestion that the research was neutral, is obviously incorrect; the participating teachers were asked to engage with the research, so that we may learn from the ways in which they teach, and the mechanisms they use to assess student learning.

It was expected that this bias would lead to the teacher recognising that what the research was really interested in, were the elements of their practice that were novel and surprising. Indeed, it was expected that, because the teacher was aware that the reason they have been asked to participate was that they had demonstrated innovative teaching practices, discussions would likely revolve around those components of the teacher's practice that were more unusual; and so the teacher would have cause to deliberately introduce ideas that may potentially be challenging to the researcher.

The nature of this interaction leads to an appreciation of the delicate balance that was required for this research to be meaningful to an audience of practitioners. While the researcher is never truly an insider, it would be valuable for her to possess some of the knowledge that might be expected of an insider. This would enable the participating teacher to explain, as though to a peer, those elements of their practice that would be recognisably innovative when considered from an insider's perspective.

Alternatively, it could be argued that there would be difficulties associated with the conduct of the present research, if the researcher had no insider knowledge. The ability to recognise the innovative, and to separate it from the mundane, was a basic requirement for the problem under consideration.

Thus, in order to appreciate the complexity of the teacher's practice, the researcher was required to occupy a number of positions that in combination offered a more informed view of the problem space. With real identities that encompass myriad roles, including citizen, student, parent, and fellow-educator, the researcher was required to consider the persona that was dominant at any one time, and to question the effect of that lens upon the data. In this case, it was not enough to make the familiar strange. Rather, there was an additional requirement that the familiar be recognised for where it has its origins, and from thence to appreciate the strange when it appeared.

3.6.3. A Focus on Pedagogy and Assessment

At this point it would be salient to reconsider the research questions, which could offer a means through which the researcher's perspective might be clarified:

1. What do secondary mathematics teachers value in student learning with mobile technologies;
2. How do traditional mathematics assessments influence teacher perceptions of the effectiveness of teaching with student-centred mobile technologies; and
3. What do mathematics teachers perceive to be the characteristics of assessment methods that enable and encourage the use of mobile technologies?

In considering the junction between pedagogy and assessment, the questions demand a viewpoint that is less personal, and more abstract. Their focus would be on the relationship, not between the teacher and his students, or between the teacher and those to whom he reports, but rather between the teacher and his craft.

The problem space is, therefore, defined in such a way that the researcher was forced to consider any preconceptions that she might have regarding mobile learning, mathematics pedagogy, and assessment - in short, her own relationship with both student-centred mobile technologies and the art of teaching mathematics. However, since the study actively sought pedagogical practices that were in their infancy and thus by definition would challenge any pre-existing assumptions about how mathematics might be taught, the issue of fighting familiarity was not so much the province of the researcher, as it was that of the respondent. With an aim of observing pedagogy and assessment in flux, the researcher need only be in a position to identify the innovation, and be able to discuss the respondent's interpretation of what was normal, and what they considered to be novelty in practice.

Somewhat serendipitously, the researcher's ability to assume the role of an insider, and to relate the observations of teacher practice to her own understanding of mathematics teaching and learning, offered advantages for this aspect of the research. In particular, it was found that it could highlight norms by omission. That is, the respondents, in making assumptions about what the researcher might and might not know regarding mathematics pedagogy and assessment, offered unique insights into what they considered to be a norm. This might manifest in a number of ways, ranging from not being mentioned through to the use of jargon or compressed explanations, or the use of expressions such as "you know".

Another aspect of the teacher's assumptions regarding the researcher must also include the extent of the shared teaching experience. This was particularly noted in a case where one teacher spoke familiarly of practices that might be considered to be pedagogically controversial, but which appeared to infer a common understanding regarding educational methods. While the teacher's thoughts regarding these practices were explored in depth, it is difficult to know whether the teacher might have canvassed these ideas in a different way, or potentially not at all, if they had assumed that the researcher might not have been sympathetic to the methods under discussion.

3.7. Data Analysis

An appreciation that the researcher necessarily introduces a flawed lens to the data collection process leads to the inevitable conclusion that the data will be presented complete with researcher bias. While all attempts were made to act in an impartial manner, it would be naïve to expect that the results of the data collection would have been the same notwithstanding the nature of the researcher's prior experience, or irrespective of who it was conducting the research.

Thus, with an acceptance that such flaws will exist, we shall draw upon Heshusius' (1994) discussion of such influences:

> What does one do after being confronted with these "subjectivities"? Does one evaluate them and try to manage and restrain them? And then believe one has the research process once again under control? (p. 18)

With an appreciation that the management of subjectivity inevitably requires a response to a wider question of whether all subjectivities are accounted for and "tamed" (Peshkin, 1988), data analysis obliges the monitoring of personal biases whilst simultaneously becoming immersed in each case study's situation. In combining audio recordings, transcripts, interview notes, observation notes and assessment documents to tell a story, it became evident that there were scenarios that were personally recognisable, and under such circumstances the process of taming the subjectivity required an appreciation that any possible "insider" understandings needed to be acknowledged and, to the extent possible, managed whilst conceding that any management is necessarily inadequate. Attempts to monitor the potential for the research to be "too much about me" (Smith, 1980, as quoted in Peshkin, 1988) thus led to a style of writing that foregrounded the respondent through the use of quotes, taken verbatim from audio transcripts. In experiencing those words, one could hear the voice that was speaking, enabling a fuller and more direct participation in the respondent's story.

Heshusius' (1994) discussion of participatory consciousness describes a "recognition of kinship" (p. 15), a

> letting go of egocentric concerns [which] does not imply direct access to some "truth", but points to a merging into a larger and more complex reality (p. 18)

and it is with this "participatory *quality* of attention" (p. 18, italics in original) that we can come to appreciate the subtleties inherent in teachers' stories. Thus it is hoped that the findings are presented in a way that is representative of each teacher's reality - or, at least, in a way that is true to each teacher's intention.

4. Findings

Examples are better than precepts for learning the arts.

- Newton*

In this study, I observed mathematics teachers' use of mobile pedagogies in seven different secondary schools. What follows comprises a series of vignettes of practices in these schools, combined with observations from the teachers themselves regarding their own use of mobile pedagogies, and their perspectives regarding bi-directional influences between pedagogy and assessment. Artefacts from both the teaching and the assessment are also included, to provide further clarity and depth to the illustration of each school's practice.

In all of the case studies, interviews and observations were carried out at the teachers' convenience. Thus there is some variation between the schools regarding what was observed, and also considerable variation in the amount of time that was available for discussion. It was also the case that, for the schools participating in the Discovery Project, interviews were conducted in combination with other researchers on the Project, and contributions from other researchers meant that the interview script deviated considerably from that presented in the Research Methodology chapter.

*As quoted in Alexanderson and Pólya (2000), p. 123

This chapter will present each case study, representing data from a single school, as a separate section. Within each case study, data from teacher interviews, class observations and document analysis will be synthesised into a narrative that aims to describe the observed characteristics of the case.

Quotes from the interviews will be used where possible, as interpretations of those quotes would likely lose more of the intended meaning. The quotes are coded according to the teacher alias, school code, recording number, and the timestamp on the recording. Thus “Holly, FHS1 0:01:57“ would indicate that:

- [Holly] the speaker was Holly,
- [FHS] the school was Farringdon High School,
- [1] this was the first recorded interview at the school, and
- [0:01:57] the timestamp on the recording was 0:01:57 (1 minute 57 seconds after the start of the recording).

In an effort to simplify the narrative, I present the research questions for each case study at the point where they are actually answered. I chose this structure because there were situations where the response to the second research question was necessary to make sense of the response to the first question, and so on.

The chapter concludes with a discussion of the commonalities and differences that were observed during preliminary analysis of the case study findings.

A brief explanation of the NSW secondary mathematics syllabus structure

All but one of the schools were in New South Wales, Australia, and so these schools shared a common mathematics syllabus. The structure of the syllabus is based around stages of achievement (NESA, n.d.a and n.d.c). In secondary school mathematics, these stages align with school years in the following way:

- Stage 4 (Years 7-8)
- Stage 5 (Years 9-10)
- Stage 6 (Years 11-12)

There is also a separate set of Mathematics Life Skills content, intended for students for whom the standard content is not appropriate.

While the Stage 4 course content is common for all Stage 4 students, Stage 5 is expressed in terms of three substages: 5.1, 5.2 and 5.3. In general, it is useful to think of Stage 5.3 as comprising the most ambitious set of outcomes for Stage 5, with Stage 5.3 content being prerequisite for entry into the more rigorous Stage 6 courses.

For Stage 6, students may elect to engage with mathematics at five different levels:

- Mathematics Standard 1 (similar to the course previously known as General 1)
- Mathematics Standard 2 (similar to the course previously known as General 2)
- Mathematics Advanced (also known as 2-Unit Mathematics)
- Mathematics Extension 1 (also known as 3-Unit Mathematics)
- Mathematics Extension 2 (also known as 4-Unit Mathematics)

In general, it is useful to think of Mathematics Standard 1 covering more basic content, and Mathematics Extension 2 being the most difficult course.

4.1. Case Study: Farringdon High School

Located in suburban Sydney, Farringdon High School is a co-educational comprehensive school catering to a relatively large Year 7-12 student population. At the time of the first interview (2016), it was mathematics teacher Holly's second year with the school, for which she had a full teaching load, with:

- Mixed-ability Year 7
- The top class in Year 8
- Year 10 5.1 - a course designed for Year 9-10 students who are working toward Year 7-8 outcomes (NESA, n.d.b)
- Year 11 2-Unit (Mathematics Advanced) - a course designed for Year 11 students with prerequisites that include most of the available outcomes for Years 9 and 10 (NESA, n.d.c)
- Year 12 General Mathematics - a course that assumes that students have achieved the outcomes of Year 10 5.1 (NESA, n.d.c).

Observations were conducted in the subsequent school year (2017), with:

- Holly's Year 8 class (2nd of five streaming tiers)
- Holly's Year 9 5.3 - the most advanced coursework for Years 9-10. Holly's class was the 6th of six 5.3 classes; there were 10 Year 9 classes in total
- Mathematics head teacher Will's Year 11 Extension 1 - the most rigorous course for Year 11, designed for students who have studied all of the available substrands for Years 9-10 (NESA, n.d.c).

As a large government school, Farringdon implemented a policy of non-specific BYOD (Bring Your Own Device) for students, and as a result students brought a range of different devices to school. Holly's experience with this diversity had made her wary of unstandardised technology, describing having a mixture of iPads and laptops in class in a previous year as a “complete disaster” (Holly, FHS1 0:01:57). In her second year, the proportion of laptops had increased, but platform differences remained, with about 25% of students using Apple Macintosh products and the remainder on PCs.

The technology was used in the first instance to provide access to a soft copy of the student’s mathematics textbook, and so “Every single teacher will say, oh, yeah, I use computers” (Holly, FHS1 0:02:40). Holly asserted that, while she herself used a lot of technology in her teaching, “the kids don’t as much as they should” (Holly, FHS1 0:01:50). In addition, she volunteered that she used Edmodo as a distribution mechanism only, describing it as

> essentially a photocopy reduction strategy, and a sharing a hyperlink very easily, and a “is all your homework in one place” strategy. So it’s an effective communication strategy … it’s management. It’s not adding value in any great ways. (Holly, FHS1 0:02:40)

Holly’s assessment of this technology as “not adding value” offered some insight into her capacity to judge technology for its augmentative benefits. In conjunction with her opinion regarding students’ underutilisation of technology, it could be inferred that she appreciated the potential for technology to enhance the teaching and learning experience for students, and thus her perspective aligned at some level with Patten et al.’s (2006) framework (see Chapter 1, Section 1.2) for categorising the functionality that technology can provide.

4.1.1. Issues With Student-Centred Technology

Holly's experiences with BYOD influenced her views regarding the practical implications of working in a classroom with a "lack of uniform platforms" (Holly, FHS1 0:06:00). She related the problem to that of students with computers in various states of disrepair, describing it as an equity issue:

> You can't mandate, in a government school, that everyone gets a state-of-the-art whatever. (Holly, FHS1 0:07:05)

To illustrate the effect of this lack of uniformity, Holly described two different classroom activities. One made use of Microsoft Excel, which was an application that was installed on all of the students' computers. Holly had access to both her school PC and her own Apple Macintosh laptop, and so was familiar with both platforms, and she prepared separate instructions for the two platforms. However, when she ran the activity in class, there were more versions of Excel than she had accounted for:

> The kids are on a Mac on a different version of Excel to my Mac. The whole menu changes. So - Year 8, we were doing a graphing activity. So I was getting them to create a pie chart, create a divided bar chart, create a line graph - and … because I'm on Excel 2012 and they are on 2014, those instructions were never valid … So it's just a bit of a minefield, where you don't have unity of technology. And that's definitely a barrier to me, to attempting lessons … I just know it's going to take twice as long [to prepare the class] because I'm going to need to support Excel 2007, Excel 2009, Excel 2013. (Holly, FHS1 0:07:55)

In contrast to installed applications, web-based activities could potentially offer more uniformity of interface, but nonetheless it was also the case that students had problems when trying to access a web-based Geogebra activity. Holly described an interactive

Geogebra demonstration, which would fill a container with “water” while simultaneously plotting a graph:

> For probably a third of the kids that didn’t work. Now, I know that the other two-thirds did not have Geogebra on their machine, so I don’t know why it didn’t work … So the more things like that happen, the less you’re likely to use, sadly. (Holly, FHS1 0:03:12)

Her attitude towards the technology was therefore conflicted. While she was aware of, and in many ways expecting, technical problems that could arise through the implementation of the activity, she was very clear that the technology was still worthwhile:

> I can see benefits. Like the rates of change thing, it was amazing being able to do that activity using an IT thing. To pour water at a constant rate into a glass, is very difficult … At the same rate as that was filling up on the screen, the graph was being plotted on the screen, at exactly the same rate. So that, to me, was an area where technology was far superior to pen and paper. (Holly, FHS1 0:10:08)

Further conflicts then arose when she had to trade off the benefits of having a technology-rich lesson against the time investment that would be required on her part.

> My concern is that there’s only a limited amount of those educational opportunities where there are those benefits, and it’s having the time to seek them out … Even if I allow half an hour to plan a lesson, which isn’t much really, that’s 2½ hours every day in planning time. And if you go down a “trying to find a technology solution” route, and after 20 minutes you’re getting nowhere, you’ve got 10 minutes left, or you’ve got no life. (Holly, FHS1 0:11:10)

It can thus be seen that Holly's attitude towards student technology use was largely pragmatic. She focused mainly on the trade-off between educational benefits, and the time investment required to circumvent the unreliable nature of immature technology. While she did mention that she did consider other factors for technology use - for example, with her lower-achieving students, she would be

> more likely to use interesting stuff. Now whether that's technology based is a whole other issue, because they are likely to be more distractible - or distracted, by technology (Holly, FHS1 0:37:40),

for the vast majority of the interview, the potential for technology to distract students was not a consideration that she particularly chose to discuss.

4.1.2. Technology for Teaching and Assessment

Holly's experience with student-centred mobile technology that could be used for formative assessment purposes ranged from applications that had a very maths-specific focus, through to generic tools that were, in her opinion, eminently unsuitable for secondary school mathematics. In one instance, she had attended professional development on a technology-based assessment tool, and found it lacking when it came to mathematical functionality:

> It's really good, and it marks it all for you, and it's wonderful, but I go to the session, and you can't put in a square root sign. You can't put in an x^2. So as soon as you see that, you go, oh, this is no good. (Holly, FHS1 0:20:40)

She had, however, adapted a variety of technology-based tools for pedagogical purposes that were in some way related to assessment.

4.1.2.1. Student Self-Assessment

Holly created Weebly websites for various topics, with “drill and practice” games for junior students to use as self-directed learning - not ostensibly for her to assess the students, “apart from me looking over kids’ shoulders” (Holly, FHS1 0:24:20), but for students to essentially self-assess their own learning needs:

> You know, here’s decimals, and here’s 10 things you need to do with decimals … What do you think you’re not that good at - and practise that. (Holly, FHS1 0:24:57)

She noted that she had only been able to do this for the younger students, having been unable to source appropriate material for more advanced mathematics.

> Because for juniors, there’s a lot of games out there, but not for seniors. And that’s a problem I think, as well - is the lack of good resources for more senior years. Because Year 7 is still on that boundary with primary. (Holly, FHS1 0:24:57)

4.1.2.2. Generic Quiz Tools

Holly also used some generic quiz-style tools, such as Socrative and Kahoot!, for both pre-assessment and to finish a topic:

> usually when I want to do something a bit of fun, and a bit of an assessment task. It’s often a sort of end of term thing. I’ll tend to do a maths question, and a “who can sing One Direction” question … maybe with a bottom class. And that’s very popular. And it’s a good way in a lesson that you probably wouldn’t get much work out of the kids, to actually get them working. (Holly, FHS1 0:19:00)

It was, however, the serendipitous acquisition of unexpected assessment information that proved to be particularly interesting. In one instance, Holly's Year 10 class collected data from an estimation exercise:

> How many lollies do you think are in the packet? There was a lot of food! How much do you think the apple weighs? (Holly, FHS1 0:27:30)

and then used the results for a subsequent class activity relating to statistical analysis. While the activity was primarily about collecting data, it actually led to Holly's realisation that her class required help with a different topic:

> There was a bit of a back story about getting a feel for the understanding of units … I think one was, how much is in a Solo [soft drink] can. And some of them put, like, 325 grams, some of them put millilitres. So there was an awareness there that, you know, they didn't know their units. This should be a capacity. It's clearly a drink. Lots of them didn't put units. So it's emphasising that we need to do more work on units. (Holly, FHS1 0:28:00)

The revelation that the students' grasp of units needed some work arose as an unplanned consequence of using technology to collate student responses. Holly noted that she had deliberately kept the question open because the class had been discussing "what makes for a good question" (Holly, FHS1 0:28:00) and as a result

> it actually revealed far more, because then we have to talk about, well, do we exclude the people who put 325g? Do we change them to millilitres? The kids who've just got 325, what do we do with that? Do we assume they mean millilitres? … So sometimes you get added benefits out of it that you weren't necessarily thinking of. (Holly, FHS1 0:28:00)

Holly's description of this scenario challenged the implicit denigration of "outmoded" drill-and-practice uses of educational technology (Doering and Veletsianos, 2009, p.81), demonstrating the value of technology as an assistant to a teacher who is able to recognise, and take advantage of, unanticipated teaching opportunities. When asked if she wouldn't normally have found out about the students' weak understanding of units in any case, Holly contended that in this situation

> it was more glaringly obvious, and therefore we had to deal with it ... Had I given them a questionnaire that said, OK here's 10 estimation questions … then I've got, like, 20 bits of paper back - and then I somehow had to collate this on the board, or whatever I'd done - then I think I would have probably just made a call and said, "OK we're going to say they're all millilitres." … The way the data was collected made it quicker, and freed up time to then actually talk about how that data doesn't work so well. (Holly, FHS1 0:30:30)

4.1.2.3. Mathematical Games

As previously mentioned, Holly created Weebly websites with sets of drill and practice games for her younger students to enrich their mathematical learning. One notable game, recommended by Holly's head teacher Will, was SolveMe Mobiles (Figure 4.1), which

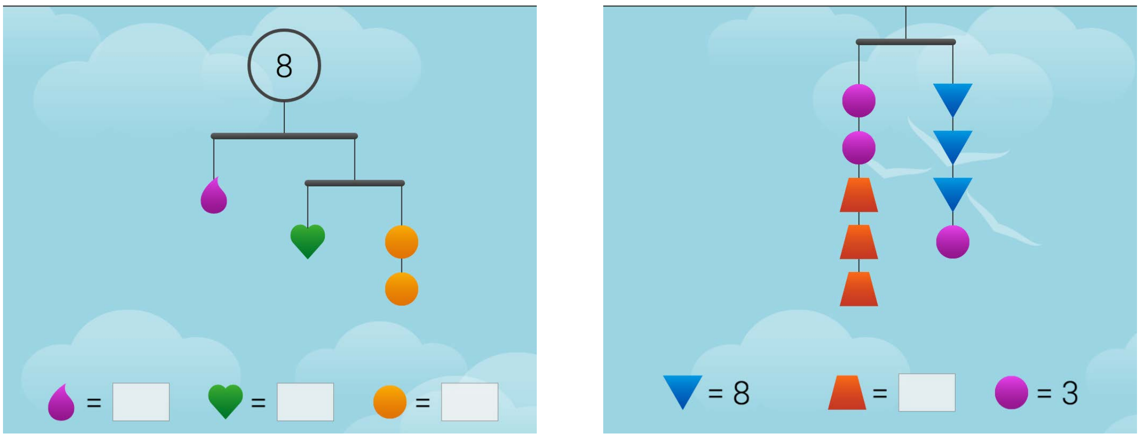


Figure 4.1. Screenshots from SolveMe Mobiles (https://solveme.edc.org/Mobiles.html).

offered simple renderings of algebraic equations in the form of a balanced "baby mobile". While the game itself was clearly intended to develop students' algebraic thinking skills, Holly discovered an additional benefit of the computer game format:

> It's like doing Angry Birds, or something … One of those online things where you unlock Level 2, then you unlock Level 3. So you can instantly see where kids are at, because the screen flashes it up. You can see they've done [levels] 1 through 48. So it's fantastic, instant assessment. And the kids think they're having fun. (Holly, FHS1 0:23:00)

While it was unclear whether Holly realised that there was assessment potential in this activity prior to trying it with her class, it was apparent that it contributed towards her enthusiasm for the game, and her intention to use it again:

> When you come across something that's really good, you go, oh that's awesome - then you do it all the time. But it's finding the things, and that's the problem. There's too many sources, too many things out there, and not enough time to check them out. (Holly, FHS1 0:23:00)

4.1.2.4. Web-based Graphing Calculators

While Holly was evidently familiar with a range of software applications, observations of her classes made it clear that her preference was to use Desmos (http://www.desmos.com) for day-to-day teaching. Thus the Desmos website was used to curate a series of questions chosen from the textbook, and Holly was able to view student work on her own screen as it was submitted.

This arrangement enabled Holly to manage her classroom in a number of different ways, with perhaps the most notable affordance being Holly's ability to use her own device to manage the learning experience. During the observation of the Year 10 5.3 class, Holly noticed a "Pause" button on her own Desmos screen (Figure 4.2). Upon clicking on it, she discovered that it disabled all of the student screens and directed the students' attention towards the teacher, prompting her to exclaim "I am in control!"

Another feature offered by Desmos was the ability to display all of the student work on the classroom's projector screen. When Holly tried this feature during the classroom observation, she was surprised to find that this function replaced all of the students' names with aliases based on the names of famous mathematicians (Figure 4.2). After some initial confusion, the benefits of the alias functionality became evident to the students and they looked both amused and relieved. The students' own screens informed them of the alias that was being used to replace their name, so they could identify their own work on the projector screen; but since nobody else would know whose submissions they were, the entire class could discuss the work without fear of embarrassing particular individuals.

In addition to the inbuilt Desmos functionality, the use of Desmos in this way allowed Holly to manage issues of device access. Students who, for whatever reason, did not have a device in class would be directed to borrow a textbook and to use it to complete the same work. During a private communication, Holly described the issues she had had with a student in another class who had been prohibited from using his mobile device. Farringdon High School had asked that all students sign an agreement regarding device use etiquette, and this particular student had violated the agreement, resulting in a year-long ban. Thus, in order to allow this student to engage with the coursework, Holly was

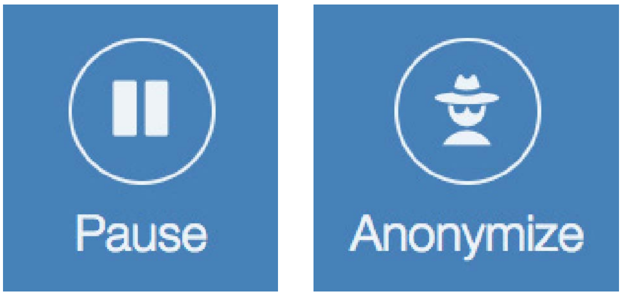


Figure 4.2. Functionality offered by Desmos.
"Pause" disables all of the student screens, and "Anonymize" allows the teacher to show student work without identifying the student.

obliged to maintain close links with the textbook; and through this means she was able to offer the same course content to all of the students in that class.

Subsequent discussions with both Holly and head teacher Will regarding the Desmos functionality noted that Desmos had evidently been designed, and was continually being modified, with reference to what mathematics teachers need. From Holly and Will's perspective, all of these features made a great deal of sense for the management of mathematics classes and the improvement of mathematics pedagogy.

4.1.3. Summative Assessment: Methods and Attitudes

Farringdon High School's formal mathematics assessments were largely traditional. With the exception of a recently introduced small-scale innovation (see Section 4.1.4),

> every single one of our formal assessment tasks … is pen-and-paper based, even in Year 11 and 12. We have no projects that we turn in on the focus studies, or anything like that. (Holly, FHS1 0:34:05)

This placed Farringdon at one end of a continuum of summative assessment methodologies, and thus this school offered an insight into the pedagogical implications of assessment that is skewed in favour of traditional examinations. From Holly's perspective, it was clear that there were aspects of student achievement that would be mandatory for success in this particular assessment regime:

> There is a big focus unfortunately in my school, on those high-stakes exams … If those kids cannot, on a piece of paper, draw a graph, on a piece of paper, solve an equation, they are not going to be successful at HSC. (Holly, FHS1 0:34:05)

It was therefore unsurprising that, at least with some of her classes, Holly felt pressured to teach to the test. Notably, she distinguished between the test and the syllabus, and indeed she made it clear that there was a difference between the recommended learning, and the subsequently valued, demonstrable skills:

> So, good example is, 2-Unit students are supposed to see the derivation and the proof of the sine rule. It's what the syllabus says. But that's never come up in the HSC. We need my kids to be able to do sine rule questions, full stop. And last year … I did the proof of the sine rule to my bottom 2-Unit class, who had no idea what was going on. I've got a high-achieving class this year, and I didn't teach it ... And that's what those kids want. Is this going to be on the test, Miss. (Holly, FHS1 0:35:05)

In addition to this, she had been led to appreciate the need to teach pedantic correctness. To satisfy the requirements of colleagues with different views of correctness in mathematical wording, she had learned that at Farringdon,

> we have a very specific way of marking assessments … things that I deem acceptable are not deemed acceptable in the [Farringdon] way. So an example would be, saying "vert opp angles are equal" is not acceptable in the [Farringdon] way. One must write, "vertically opposite angles are equal", depending on the teacher that's marking. Some teachers would accept that, and others wouldn't. (Holly, FHS1 0:46:40)

These factors all contributed to a pedagogy that favoured the demonstration of competence, and the attainment of a good HSC result; and indeed Holly regularly referred to HSC questions to gauge the level of performance that would be expected of her students:

> I am spending a lot of time looking at HSC questions, and our past questions, to see, how could we assess this. How do we want our answers to look … We're

> always having an exam-style question [when teaching], which is from an exam … because we push a level higher. (Holly, FHS1 0:47:50)

Interestingly, the exam focus has, in one instance, had unsatisfactory outcomes for a situation where students were being tested for the development of relational understanding, as defined by Skemp (1976). Holly described the unreasonableness of testing students with a question that was different to that prescribed by the syllabus:

> I had a bottom class, and these guys could barely cover the syllabus. So an example would be, you know capture-recapture? You capture 20 fish, you tag them … The syllabus says, you should be able to use this technique to estimate the number of fish in the lake.
>
> And we tested it as a reverse question, which was, "There's 2000 fish in the lake, you capture 25, you release them. When you come back and capture 40, how many will have tags?" So it's kind of turned it around. And that's off the syllabus. And I felt, not for my kids. I said to them, "On the syllabus, this is the only type of question you will get." … And we do that a little bit. Our exams are usually harder. (Holly, FHS1 0:49:20)

As a consequence of this examination focus, Holly's students were regularly exposed to material that actively prepared them for the HSC. It was particularly notable that the HSC had considerable influence on instruction even when it was a distant proposition, as demonstrated by Holly's choices when teaching Year 10:

> These 5.1 kids, if they stay in maths, are doing General … And I guess with those kids, my eye is so much on that General syllabus, it's not really on the Year 10 syllabus. It's on where they're going, where do we need to get them to. (Holly, FHS1 0:32:40)

However, Holly also believed that she had more freedom to choose appropriate learning activities for the lower-achieving classes, since there was a sense that they were less academically focused. In comparison to her current high-achieving Year 11 2-Unit class,

> last year, when I had General 5, bottom General class, I saw my job in a different way. It was preparing for the HSC, and the world. So I was interested in, will these kids have a vague idea. I told them a hundred times, how expensive credit cards were, how bad gambling is. My emphasis was more life skills, even though it's still an HSC course.
>
> And with these 10 5.1 kids, I feel more at liberty to focus on those external life elements, and less pressure to slavishly follow the - not the syllabus, because the syllabus has some good stuff in it, but slavishly teach to the test. (Holly, FHS1 0:36:25)

The relative aptitudes of her students presented a conundrum for Holly when selecting learning activities for her classes. With the lower-achieving class,

> I'm more likely to go, take more of a risk … with a middle class I feel less able to take risks. Because those kids need all the help they can get, just to get through the stuff they have to get through. With the bottom class, I think it's more about preparing them for life. (Holly, FHS1 0:37:55)

Interestingly, Holly's choices were also more adventurous when she had a high-achieving class:

> With the top class, they'll probably get it anyway. So, you know - that's my perception. (Holly, FHS1 0:37:55)

This assessment of her students' needs placed Holly's choices of classroom activity on a spectrum, ranging from

- Innovative, for lower-achieving students; through
- Conservative, for middle classes; and
- Back to innovative, for higher-achieving students.

Her selections were thus coloured by her understanding of the students' needs with respect to their academic careers, balanced against the life skills that she believed were important for their future in the real world.

4.1.4. Summative Assessment with Technology

While Farringdon High School's mathematics department conducted summative assessments exclusively through examinations, a small number of these assessments for Years 9 and 10 were conducted through Mathletics online, to supplement the usual pen-and-paper offering (Figure 4.3).

The Mathletics test was introduced as a way of inserting an examination for a single topic into the assessment schedule. Its purpose was ostensibly to reduce the burden on the next pen-and-paper examination:

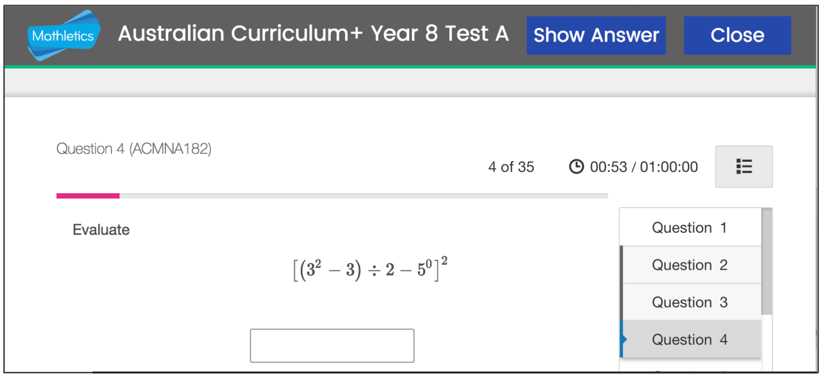


Figure 4.3. Detail from sample Mathletics test. (https://au.mathletics.com/tests).

> Depending on the timing of the exams, you might have five topics stacked up and there's an exam coming. So you can't get five in. So this was a way to assess another topic. (Holly, FHS1 0:14:30)

However, the benefits of automatic marking for the Mathletics test were offset by implementation difficulties:

> So there were issues with: kids couldn't get online, logins didn't work, and you're trying to do a timed test … you need a separate teacher, which has a funding implication, in a room to send the kids to, who can't get online. … And those kids have a bit of a hectic start to their assessment test. They're running over the school, because it - or it's crashed halfway, too. (Holly, FHS1 0:15:34)

In addition, the teachers were dissatisfied with the level of control they could have over the test content.

> On Mathletics you can't pick the questions. You basically get, like, 10 of the same question … So we did it for trig, but it was like the most basic trig questions. It was like right-angled triangles. There was no unit circle. … In our next [paper examination] we've now put some hard trig questions in, just so we've done some. (Holly, FHS1 0:15:34)

4.1.5. Exploring Mathematics

Although Farringdon High School's mathematics assessments were conducted exclusively through examinations, and the mathematics pedagogy focused largely on skills that would be relevant for being assessed in this way, mathematics head teacher Will also created a Stage 5 mathematics course with a markedly different focus. Dubbed "Exploring

Mathematics", the course is a half-semester elective dedicated to mathematics that is not included in the NSW mathematics curriculum. The course program is included in Appendix A-7, and its assessment outline in Appendix A-8.

In order to explain what it was that the course offered, Will brought up an image that demonstrated links between the different branches of mathematics (Figure 4.4). With school mathematics occupying a relatively small area on this map, Will was able to create an extension course that did not overlap any of the content that would be covered by the syllabus; and he was able to do this because the NSW Education Standards Authority [NESA] allows schools to devise School Developed Board Endorsed courses for Stage 5 (NESA, 2018), and because the school was so large that he felt sure that there would be enough interested students. However, Will was also careful to limit the intake for the course, so that student numbers would be maintained for elective subjects such as Creative and Performing Arts (CAPA), to ensure that teachers of those subjects would not be losing their jobs to yet another mathematics course.

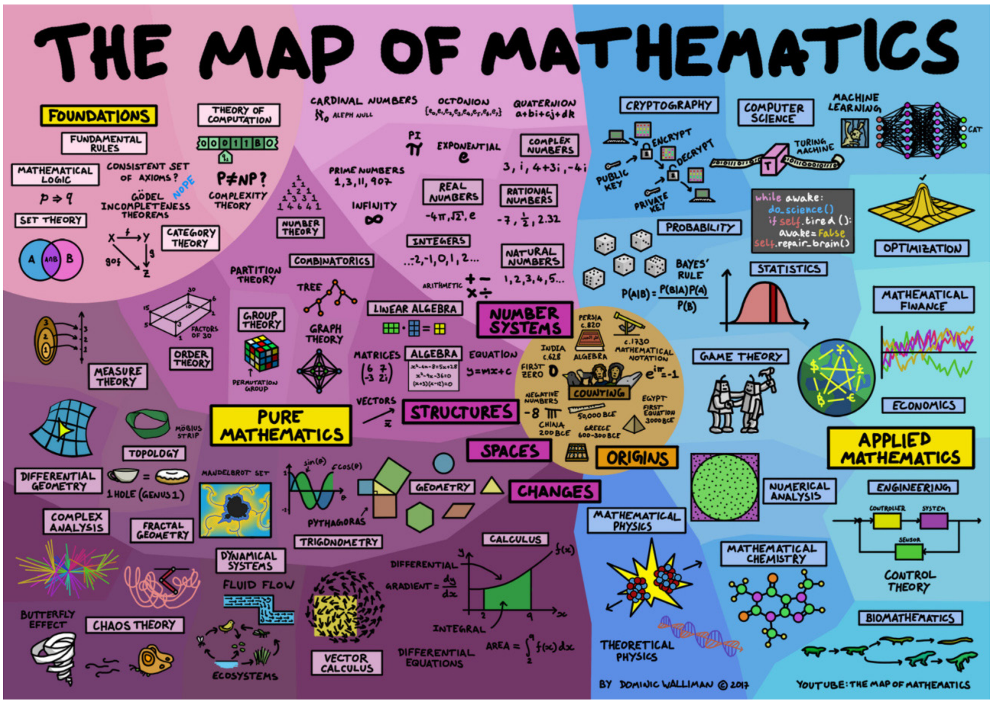
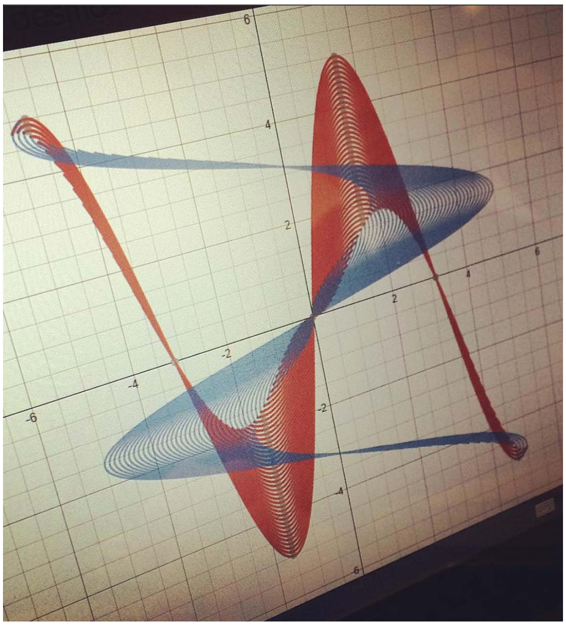


Figure 4.4. The Map of Mathematics. (https://denisegaskins.com/2017/02/06/)

With an emphasis on "branches of mathematics that are not understood through repetitive exercises, nor assessed in traditional examination formats" (Appendix A-7), the existence of such a course indicated an appreciation that school mathematics was expected to be repetitive, and that mathematics assessments were expected to be traditional. The Exploring Mathematics course countered these expectations with content that included "Beauty", "Cryptography", "Paradoxes" and "Play", demonstrating the breadth of what mathematics actually covers and offering perspectives on the subject that might be more fun and engaging.

To complement the course offerings, assessments in Exploring Mathematics included the creation of an individual artwork that would demonstrate a link between mathematics and beauty, and the production of a group video presentation about a mathematical concept. Students produced some extraordinary work for these assessment tasks, as shown in Figure 4.5, offering indications that project work could prompt an in-depth appreciation of mathematics for its subjective beauty, and not just its objective correctness. However, it was notable that, despite apparent resistance to the traditional examination format, the Exploring Mathematics assessment schedule still included two quizzes - a circumstance that raises questions regarding whether mathematics is actually generally amenable to alternative assessment. Indeed, even with rubrics for determining the quality of student work, Will noted that it was not easy to mark the project-based tasks, and the length of time required to do so "was considerable. No two ways about that." (Will, FHS, personal communication)

While the Exploring Mathematics course was relatively new, having been run for the first time in 2014, its effects were observed in the attitudes of past students towards their mathematical learning. Observations in Will's Year 11 Extension 1 class noted that, while the majority of the students were occupied in completing previously set textbook exercises for the current calculus module, there was one student who was playing with a graphing application on his laptop. Students sitting nearby would ask him to change the graph in some way ("can you make it look like this?") and he would proceed to experiment with the parameters of the graph to match the request. In subsequent discussions with Will, it was evident that Will was not concerned about the off-task behaviour, ascribing it to this student's attendance at the Exploring Mathematics course in a previous year and noting that he was aware of this student's preference for learning through experimentation.



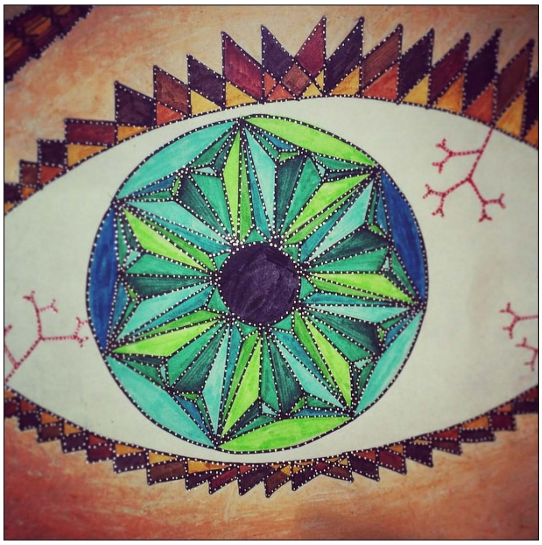


Figure 4.5. Project work from the Farringdon High School "Exploring Mathematics" course.

4.1.6. Influences on Teacher Actions

> ➢ **Research Question 3**
>
> What do mathematics teachers perceive to be the characteristics of assessment methods that enable and encourage the use of mobile technologies?

Despite the existence of the Exploring Mathematics course, Farringdon High School maintained a relatively traditional position regarding what it meant to teach and learn mathematics. Indeed, Exploring Mathematics offered a contrast that served to highlight the difference between the mathematics that was chosen for its potential to be interesting and engaging, and the mathematics that was considered to be foundational for life after school.

Mathematics education at Farringdon was particularly notable for the lack of project-based tasks in all but the Exploring Mathematics course. Along with Holly's dissatisfaction regarding the affordances of the Mathletics topic test, there was a sense that assessments should not be treated lightly, and so any changes to the prevailing paper examination culture needed to be dependable, robust, and justifiable. With assessment methods that permit the use of mobile technologies being considered to be either novel or unreliable, there appeared to be an unwillingness to experiment with a system that had, to date, been adequate for the school's needs.

> ➢ **Research Question 1**
>
> What do secondary mathematics teachers value in student learning with mobile technologies?

While technology was evidently used for creative endeavours in some of Farringdon High School's mathematics teaching and learning contexts, Holly's attitude towards student-centred technology demonstrated the key position occupied by pragmatism, both for the teacher's time management, and for what students would value in a school culture that maintained a primary focus on academic achievement. With constraints ranging from issues over which the teacher had little control, such as disruptions occasioned by technological malfunctions, through to professional concerns regarding what was best for her students, Holly's choices demonstrated a considered approach that appraised technology for its potential instability, as well as its ability to support both practical and affective outcomes.

In learning from Holly's experience, there was much to be said for careful selection of the circumstances under which a technology-rich activity might be introduced. Indeed, the introduction of the activity was a separate consideration to its subsequent larger-scale implementation, as could be seen by Holly's non-selective use of Desmos, Weebly and Edmodo, and the school's choice to provide all students with soft-copy textbooks - an attitude that suggested that the school's experience with these applications differed markedly from Holly's observations regarding the Mathletics test. The use of reliable, mature technology was a different matter from trialling activities that had not yet been proven. Such a view was also relatable to Holly's perception that there was not enough time to identify good resources, and her appreciation when a trusted colleague was able to recommend something that was worthwhile - a kind of professional learning that has been noted as being particularly useful for practising teachers:

> [We assume that] teachers are busy and do not have the time to devise and document lessons for themselves and so often seek suggestions of lesson ideas that have been developed by others. We do not assume that teachers cannot create such tasks for themselves but it is our experience that teachers welcome suggestions of the elements of lessons that can facilitate their work. (Sullivan et al., 2015)

➢ Research Question 2

How do traditional mathematics assessments influence teacher perceptions of the effectiveness of teaching with student-centred mobile technologies?

It was significant for Holly's pedagogy that her willingness to take risks was coloured by her judgements regarding the students' abilities, and it was this consideration that particularly informed Holly's attitude towards student-centred technology. In effect, the technology was considered to be a powerful but volatile component in the classroom, which could enhance the learning experience - but these gains had to be weighed against the possibility that time would be wasted because the technology was not sufficiently robust. With such potential for valuable class time to be compromised, it was unsurprising that Holly was comparatively reluctant to experiment when teaching a "middle" class that aspired to the same qualifications as more academically highly-achieving students.

A school culture that particularly values academic success, as demonstrated by good results in traditional assessments, would be consistent with the co-opting of student-centred technology for the purposes of helping students to develop demonstrable competence. Holly's obligations to her students aligned well with technology that provided her with feedback regarding how well her students had worked, and applications that might help her to diagnose any weaknesses in their present understanding. She could also justify the use of software that would assist with graphing, data collection and management, and mathematical simulations - all of which were applications that would have a direct association with mathematical sense-making.

While there was little that was particularly radical in Holly's use of technology, her insights into how student-centred technology could support the teaching and learning experience illuminated aspects of the functionality which went beyond what the technology would offer at face value. The ability to gain valuable formative assessment data at a glance proved to be a persuasive point in favour of several of her technology-enabled student activities. In addition to Desmos, there was the "baby mobile" application, which provided indications of student progress that were a natural consequence of the game-like structure of the activity; and there was a class-wide data collation activity which unearthed a common student misunderstanding, subsequently leading to a productive class discussion.

It was notable that none of these applications took advantage of the breadth of possibility that might be associated with mobile learning. Indeed, if we consider a primary contribution of mobile learning as being its ability to support students' development of 21st-century skills, "rather than always being inhibited by externally defined learning goals and resources" (Milrad et al., 2013), then the case for Holly's technology usage patterns was not particularly compelling. The instruction remained teacher-directed, and aligned with examinable syllabus outcomes which are, by their very nature, externally defined. Such teaching and learning contrasted with the experimentation that was encouraged in the Exploring Mathematics course, which whilst having greater potential for authenticity, collaboration, and personalisation in students' learning, was yet deliberately off the syllabus and thus had no externally-defined goals to attain.

In a culture where student work was valued and assessed for its conformance to a teachable ideal, it was unsurprising that the incentive to consider alternative pedagogies was considerably reduced. Indeed, Holly's interpretation of the philosophical question "if you were able to change something about how we assess, what would you like to see changed?" demonstrated that the school's culture had shaped her focus:

> Those 10 5.1 kids, we are assessing things from the 5.1 syllabus, which are very limited. We are also teaching them about half of the 5.2 course, yet not assessing

> that. So I would like to see some of that assessed. Because some of my kids got, like, 85% on the 5.1 exam, so I know they can do some of the harder stuff …
>
> We are not putting it in the test, and I think we are not putting it in because we don't want to make the kids feel they're crap. But then if we're only assessing them on the really basic stuff, then they're not really getting enough feedback, certainly going into the future. Because that 5.1 syllabus is not preparing them for a General 2 syllabus, at all. (Holly, FHS1 0:52:44)

To appreciate the significance of Holly's response, I shall here revisit another statement she had made regarding her lower-achieving classes:

> when I had General 5, bottom General class, I saw my job in a different way. It was preparing for the HSC, and the world. So I was interested in, will these kids have a vague idea. I told them a hundred times, how expensive credit cards were, how bad gambling is. My emphasis was more life skills, even though it's still an HSC course. (Holly, FHS1 0:36:25)

The juxtaposition of these two viewpoints helps to expose the subtleties of the nexus between pedagogy and assessment. With no apparent cognitive dissonance, Holly was able to articulate the importance of life-skills development for these students, and yet discuss shortcomings in the students' assessment in terms of its lack of rigour and subsequent inadequacy for HSC preparation. There was, therefore, a sense that, irrespective of the value that Holly placed on the development of life skills, it was yet of primary importance that students learn to value purely academic achievement - and that they realise that those academic abilities are valued, both by the school and by society.

4.2. Case Study: St Johns Wood Catholic College

St Johns Wood Catholic College is a co-educational Catholic Diocesan school for Years 7 - 10. It is located in the western suburbs of Sydney, and was one of two lighthouse schools chosen by the ARC Discovery Project for its championing of teaching and learning with mobile technology. Interviews and observations were carried out with three members of the school leadership team (Matthew, Mark and Luke), a science teacher (Sarah), and a mathematics teacher (Martha). While Sarah was a science teacher, I felt that her experience teaching with student-centred mobile technologies could inform the overall picture of the school and its support for mobile pedagogies. There was also a semi-structured interview attended by four students.

Despite the imposition of school fees, St Johns Wood drew its clientele from the surrounding lower socioeconomic area, and so it was unsurprising that the school's requirement that students purchase iPads for school use proved to be financially problematic for some families:

> The cost would be a bit of a barrier. The pricing of the iPads has dramatically increased. We were able to say … get the iPad 2, and they weren't that expensive. … The new models that are out now, are all starting to be pretty pricey. (Matthew, SJW1 0:13:00)

However, the school was adamant that the choice to stipulate a standard device was a worthwhile decision.

> If we didn't tackle it in a structured way to begin with, when the technology first started to come out, it would have filtered in regardless. They would've been using it at home. They would've, along the way, kids with dribs and drabs would have

> been bringing it in. It wouldn't have been a structured rollout, a controlled thing. It would have been a monster that developed on its own. (Mark, SJW1 0:01:22)

It was therefore the case that all students at St Johns Wood owned iPads, and there was a sense that the students understood that their iPads were both a privilege and a responsibility. The teachers felt that the ownership engendered pride in the students (Matthew, SJW1 0:37:30), and noted that the students appreciated the capabilities of the device, understanding its dual purpose for learning and leisure (Luke, SJW1 0:37:58) and enjoying their ability to do things that "amaze their parents" (Mark, SJW1 0:39:04).

The leadership team at St Johns Wood believed that the technology-rich environment was fundamental to the preparation of students for the 21st-century workplace. The rationale was twofold; firstly, there was a philosophical position that the school needed to foster the development of creativity, and support "those higher order thinking skills in Bloom's taxonomy" (Matthew, SJW1 0:17:45). In particular, although the school mandated a set of standard applications for all students to install, students were encouraged to exercise their creativity in choosing, and potentially discovering, applications that they might prefer to use - an idea that also related somewhat to the second pedagogical reason for introducing iPads, which was to teach students to be self-sufficient in their learning:

> We are now trying to teach, or tell the students, that look, learning doesn't stop when they leave school. It's not only confined to the classroom. Because in the 20 years ahead, within the workplace, they will have to be self-learners. And technology, the way we use it, I think provides the perfect platform, a ground for them to actually develop those skills of teaching ourselves. And a lot of the things that I actually have done, most of the things actually are self-taught. And I think if we don't pass that information or that sort of concept to the student then

> they'll be lost, themselves, when they get to the workplace. Because it's constantly changing. (Luke, SJW1 0:03:57)

In the six years since the introduction of iPads, St Johns Wood had seen an evolution in pedagogy that has been largely supported by teacher training conducted by a core team of technology-literate staff. With some initial reluctance to fully embrace the capabilities of networked devices, over time, more teachers had become accustomed to the ways of working that were enabled by the technology:

> Initially it was, for a teacher that wasn't that confident, "These kids are using this more than I thought. They're doing things that I'm not too sure about." … [The teacher might say] "Do some work on the iPad, but print it and give it to me to mark" - you know, that doesn't happen too much now. [Now their] response is, share it with Google Drive or email. (Mark, SJW1 0:16:57)

The teacher training initially involved a direct instruction model of professional development, which was subsequently found to be lacking in accountability:

> Traditionally we used to have staff meet in sessions where we showed them, can you do this now, but there was no way of measuring whether they were taking it in, and whether they themselves were competent or not. (Luke, SJW1 0:08:05)

Since that time, the school had instituted a buddy system whereby all members of the teaching staff would be allocated a "buddy", who was responsible for ensuring that the requisite training had occurred.

> We buddy up based on ability. We also [buddy up people who] would be honest with each other … [Luke and I] would take the two staff members that would struggle. It is mixed ability … It's really important that the buddies see the value

> of it. So we wouldn't have two staff members that wouldn't necessarily take it seriously, buddy up, because they'll be like, "Can you do that - Yep - I'll sign you off." There's no proving involved in it. (Mark, SJW1 0:09:27)

4.2.1. Innovation in Pedagogy

St Johns Wood was originally established in 1962 (school website), and carries with it a history of traditional pedagogies. Despite six years of operation with standardised student-centred technology, students engaged with a curriculum that differed little from that offered in other Catholic Diocesan schools. Indeed, as a Years 7 - 10 school, there was an appreciation that St Johns Wood must strictly conform to a standard syllabus structure, so that schools accepting the Year 10 graduates were able to assume their socialisation to orthodox teaching practices, and the coverage of typical content in the junior high school years.

It was therefore unsurprising that the technology use at St Johns Wood tended to favour management practices that allowed teachers to deliver content and collect student work more efficiently. At the time of the observations, the school was introducing Stile, a student worksheet management system which allowed teachers to both set student work and receive completed work online. Another instance of teacher-led technology use was the example given of a French teacher who used technology to deliver audio content to her students.

> [This French teacher's] entry to using the device was … "Oh, my throat's getting sore, I want to speak to the kids, how can I use these devices?" So she was because it was a speaking part, so she would say something in French and they would have to give the right example. (Mark, SJW1 0:21:28)

However, following her successful use of the iPad for providing recorded speech to her students, the French teacher began to appreciate the capability of the device, resulting ultimately in a significant change to her pedagogy.

> The task has changed so much that the original task was, she just recorded herself, and the kids would listen to it on the iPad. But now it's … the kids record themselves, share it with each other, share it back to the teacher. (Mark, SJW1 0:21:28)

Students' "teaching" was also evident in mathematics, with students in some classes expected to explain their thinking on individual Google Docs, which were also shared with the teacher.

> At the end of every single lesson, I get them to get on to that Google Doc and just update it with whatever information they learnt … It can only be one point. Like it doesn't matter if they end up writing a paragraph or one sentence, even take a picture of something that they thought was interesting. (Martha, SJW3 0:11:32)

4.2.2. Multiple Uses for an Online Quiz

During the second visit to the school, a science lesson was observed in which students revised content knowledge through the online quiz application Kahoot!. The teacher had intended to use this lesson prior to the students' examinations, but had run out of time.

> That lesson was planned to be earlier. But things come up in schools, and we missed our lesson that we weren't allowed to do it. And I'm like, I made this. I'm not wasting it. So that was intended. Schools are schools. Things come up, and you can't always get things in. (Sarah, SJW2 0:08:45)

While the lesson had been designed for exam revision, it was evident that the teacher had expected it to increase students' engagement with the content in question. Despite the intensity of the questioning, there was a sense that the quiz was intended to be "a bit of fun" (Sarah, SJW2 0:03:54) and so the students did not appear to feel pressured, and indeed were clearly enjoying the class. The only apparent pressure upon the students was self-induced, with some students striving to maintain an unbroken record of correct answers.

> Engagement that they're trying to get up on that leader board, kind of thing. Like I know that R-- definitely - he wanted to have that streak going, we heard him say it at one point … So I think that kind of - it brought in that kind of social aspect that they know, into the game and into questions, but it's educational as well. So it's kind of motivating them in that way. (Sarah, SJW2 0:08:07)

While there were students who engaged with the quiz in isolation, there were others who would discuss the answers with their neighbours, and overall the class was both noisy and social. Although active encouragement of student discussion was not observed during the class, students were evidently familiar with what was considered to be appropriate behaviour during the quiz, and the subsequent interview clarified the teacher's endorsement of the deliberations.

> I think it more provokes a lot of discussion and thought for themself, rather than me just drilling drilling drilling at them. Like it lets them have some time to process some of their own thoughts … because they would then discuss - like I don't mind if they're discussing with their friends about [the answers]. (Sarah, SJW2 0:07:03)

Indeed, the teacher considered the student discussions to be one of the most valuable aspects of the activity. Combined with the requirement that students provide answers, and the competition providing some excitement, the online quiz gave the teacher the means to conduct an engaging revision lesson. Moreover, the method of delivery had the added benefit of automatically recording all of the results in great detail, which were subsequently made available to the teacher.

> I can go back and I've downloaded that report … because, up on the TV, it only shows you the top five, but then I can have access to how each of them went the whole way through. (Sarah, SJW2 0:05:19)

4.2.3. Formative Assessment

With evidence of significant variation in the students' performance, Sarah was able to identify students who appeared to need more help, and act accordingly:

> I would have a chat with them to see, were you taking that seriously, were you just mucking around, having a chat with friends, just to make them realise (Sarah, SJW2 0:06:29)

as well as note overall trends in the students' retention of the subject matter.

> The stuff about the valency stuff, that was really early in the term. So I was like, oh, OK, they've forgotten … I specifically made sure that I worded things differently to see if they then had a conceptual understanding of the topic rather than just kind of rote learning exactly what was said. (Sarah, SJW2 0:19:46)

It was particularly notable that the results from Kahoot!, and other online activities such as Manga High, were retained by the teachers at St Johns Wood as informal marks associated with individual students.

> There are, on Manga High, all the activities that they complete on Manga High, their marks are shown to the teachers, and you collect those marks. (Martha, SJW3 0:09:40)

These marks, and marks from other assessments such as Progressive Achievement Tests (PAT tests) purchased from the Australian Council for Educational Research (ACER), contributed towards an "informal" mark that teachers used to guide their judgements regarding student achievement; thus blurring the distinction between formative and summative assessment, as they were evidently used for both purposes.

The grey area occupied by the "informal assessments" was particularly notable for its influence over teacher perceptions. There was a sense that, while the actual marks may not be aggregated in a formalised way, teachers would nevertheless be influenced by the results from the informal assessments, and would begin to develop an idea of each student's capabilities and level of engagement. In effect, the teachers appeared to be using the assessment results fluidly to inform fairly coarse-grained opinions of where students stood within the class, without necessarily consciously establishing relative ranking:

> Sarah: I'll put [the reports from Kahoot!] on my chronicle as an informal mark.
>
> PK: OK … Would you, as an example, use it to group people for the next task?
>
> Sarah: Yeah, I can. Yeah. So I have all - I keep a record of all the different tasks that we've done, in different things, I will - yeah, give them different, think about who to put together - yeah, definitely. Because we also use our PAT data. Use stuff that I can group them together, yeah. (Sarah, SJW2 0:05:50)

4.2.4. Summative Assessment

As a 7-10 school, St Johns Wood graduated students before their HSC years and so was largely unaffected by assessment regimes that were external to the school. It was therefore initially somewhat unexpected that, despite the school's endorsement of creativity and resourcefulness, the summative assessment culture for mathematics was largely traditional, with closed-book examinations, and informal marks given for bookwork and the completion of class activities.

The bookwork assessments for mainstream students appeared to comprise satisfactory participation in online activities, the completion of work set in class, and the maintenance of a learning journal in Google Docs. This bookwork component included activities that could be classified as project work, with students free to use their applications of choice to present reports.

Though used summatively, the book mark included subjectively graded components. This contrasted with the school's strong focus on passing examinations, with an urgency and importance attached to the examination schedule that was evident throughout the teacher interviews.

> It's going to be really interesting for next term, preparation for their yearlies, that it's a nine-week term … So our Year 10s finish a little bit earlier, and so that means their reports need to be written a lot sooner, for a nine week term, that means the yearly exams are going to have to be a lot sooner, and so it's going to be quite - very interesting at the beginning of next term, to see if there's a dramatic shift straight away, or if it slowly builds up. (Mark, SJW1 0:19:40)

Preparation for exams saw teachers revert to familiar routines and direct instruction, a phenomenon that was particularly noted by the leadership team as they made their rounds through the school.

> Teaching does change when you're trying to teach for that test. We've noticed that when we're on our walk-throughs … Yeah, every day, and we notice that they're up there and they're doing a lot of the revising up on the board, and it's more the teacher-centred, the questions and we're putting notes, this is what you need to know type thing. We've noticed that, it really has taken away from that different learning. (Matthew, SJW1 0:19:04)

While the exam preparation did not necessarily align with the school's professed values, it was not judged to be a wholly negative development; as teachers themselves, the leadership team understood the reasoning behind the shift in teaching practice and were sympathetic to the motivation. Indeed, as exams approached, explicit exam preparation was also justified as the students' preferred lesson delivery method.

> I think the students also might like that revision session. Can be useful revision. (Luke, SJW1 0:19:30)

However, there was also an acknowledgement that the examination culture was not appropriate for all students. As a Diocesan school, St Johns Wood maintained an emphasis on pastoral care, and professed an undertaking to

> maintain the Franciscan spirit of simplicity, acceptance of all and a deep personal love of Jesus. Indeed the handing on of the values has a very important part in the life of the students. The strength of the school lies in the students, in their openness, the joy they have of life, their friendliness and optimism. (school website)

In its “acceptance of all”, St Johns Wood welcomed a large variety of students, and had identified a number of these students as having special needs. Their mathematics teacher noted the difficulty of assessing these students under examination conditions.

> A lot of [special needs] students obviously are a little anxious … and they don’t really perform so well under exam conditions. Like, they’re obviously, they feel like they’re under pressure, they don’t perform as well. And honestly in the classroom, they’re able to perform so much better, and they’re able to explain it, but when they’re, obviously, sitting an exam, or completing an exam, under exam conditions, they’re not, they’re not concentrating so well. (Martha, SJW3 0:10:37)

With the special needs students, the teacher adapted assessments to allow them to achieve. In one instance, a student who was unable to read or write had mathematics assessments conducted as one-on-one interviews while using the iPad.

> Most of the time he watches videos, or gets the iPad to read to him … To complete an assessment, at the moment, actually every time it’s an assignment, so every time he reaches a question, I’m not giving him the answers. I’m showing him a video … he will watch it, explain what he understood from it, after which he’s actually given a mark. (Martha, SJW3 0:20:10)

However, notwithstanding concessions made to cater to different learners, the school’s assessment regime maintained the supremacy of the traditional examination format. Indeed, there was every indication that the teachers considered the ability to pass examinations to be a necessary life skill that the school was obliged to teach. In mathematics, the idea of teaching for assessable competency was a common thread that gave purpose to all mathematics lessons and justified all of the teaching strategies employed, with the examination at the end of a semester informing what was valued for the formative assessments conducted throughout.

> PK: If you were assessing your students informally in class, do you value the sort of thing that they will need to pass exams, or do you value the things they will need to get through life?
>
> Martha: Honestly, both. Because to get through life, obviously you have to pass your exams. Yeah. Like, students obviously, they need to pass in order to - you know - get to where they want to get to.
>
> PK: So there's a pragmatism in it.
>
> Martha: Yes. Yeah, both. (SJW3 0:14:20)

The appreciation that the students would eventually need to perform under examination conditions created a situation whereby examination conditions were replicated for teaching and learning.

> Actually, every time I give them any worksheet, or any questions, I usually count up the number of questions that [are on the worksheet] and I give them … usually, to be honest, a minute per question. If not, sometimes I add an extra few minutes. And I tell them, this is the amount of time [to do those] questions. And I stop them, and they ask, "Miss, that's not enough time. We didn't finish." … They need to be able to operate, to work a bit faster. (Martha, SJW3 0:16:25)

The need to perform under timed conditions also led to an increased emphasis on direct instruction:

> [With students who need to work faster] we go through different techniques on how to answer certain questions (Martha, SJW3 0:17:19)

including direct instruction regarding techniques that would likely have limited applicability outside of examination conditions.

> For example, if there's a question, it's got different numbers as the options, we try and tell them maybe, try and eliminate the ones that you don't think are all right. And try and figure out which answer it is from that. Just depending on the question. (Martha, SJW3 0:17:24)

4.2.5. Students and Technology

While there was an awareness that mathematics exam-taking methods needed to be explicitly taught to students, this emphasis was divorced from the technology focus. As an example, despite the widespread use of Kahoot!, the mathematics teacher was unable to identify apps that she would use to help students to improve their strategies for approaching multiple-choice questions (Martha, SJW3 0:17:51). Indeed, it was particularly notable that the higher-achieving students, who were perhaps more likely to be interested in doing well in examinations, were not using apps to develop their exam-taking technique, despite having been identified as being the most promising candidates for technology use in class:

> PK: So when you've got a new app that you'd like to try, what class would you try it with?
>
> Martha: My top class … because they - like they've got - like with the mixed ability, for some of them anyway, some of them have short attention spans. They'll

> lose it as soon as they're not able to do something. Pretty soon they'll start chatting … But with my top class, they'll still be doing the right thing. And if they finish, they'll tell me. "Done." (SJW3 0:17:59)

However, there were indications that the higher-achieving students were not limited by the teacher's choice of apps. These students had been observed to be more self-directed, with apparent confidence in their ability to work through any problems:

> [Students in the top class] use videos if they're trying to figure out something. With the top class I've noticed, at home if they're struggling, they're the ones that actually go up, go on their iPads and search. (Martha, SJW3 0:21:17)

Some students also noted that they used the device to ask fellow students for help.

> We communicate with each other. So we use apps on the iPad … so if I have a question, I might ask A--, and A-- might be able to answer me. (Student 0:19:54)

This self-reliance was a characteristic that was not observed in other students in the school; and indeed it was particularly striking when the higher-achieving students' use of technology was contrasted with the technology literacy of the special needs students, who appeared to struggle with the extra layer of complexity.

> We have the assignment for [the special needs students] to complete, and it was uploaded on Moodle and were asked to complete it and hand it in by a certain date. And I struggled actually to collect most of it by the end. So, and the second time around I decided just print it and they can complete on paper … and that's when I actually had everyone's. (Martha, SJW3 0:04:10)

4.2.6. Implications of Technology Use

> **➢ Research Question 3**
>
> What do mathematics teachers perceive to be the characteristics of assessment methods that enable and encourage the use of mobile technologies?

There are several observable and separable strands in the relationship between technology and assessment at St Johns Wood. There was an acknowledgement that technology could be used as an affordance when assessing for understanding, a concession that was accepted for the grading of the achievements of a special needs student; but also an appreciation that, for the special needs students, technology could be a complicating factor when requesting work items. There was also the use of technology for the teacher to acquire ongoing formative feedback, which could be used to informally judge students' achievements as well as ascertain whether or not a lesson had been successful overall.

A second insight offered by St Johns Wood was the effect of the teachers' professional development program, and the structures that were put in place to ensure that the teachers would learn to use the technology effectively when teaching. The informal peer assessment arrangement was deemed necessary for teachers to take their education in technology use seriously; and the lack of success with a direct instructional model, and its subsequent replacement with a buddy system that had built-in accountability measures, demonstrated the leadership team's own realisation that assessment was a mandatory component for new knowledge to be successfully broadcast. Indeed, it could be seen that, even with the original direct instruction arrangement, formative assessment did occur, as there was an appreciation that the model was not working as well as they had hoped, and therefore the pedagogy needed to change.

> ➢ **Research Question 1**
>
> What do secondary mathematics teachers value in student learning with mobile technologies?

At St Johns Wood, it was particularly interesting that the mathematics teacher noted the correlation between the students' ability levels and their own self-directed use of technology to further their understanding. There was therefore some suggestion that the ways in which students used the technology demonstrated their levels of interest and achievement. From offering alternative ways to demonstrate competence through to being a tool that could promote learning, the devices gave the students the opportunity to effectively self-assess, and in the process define their own level of engagement.

With the competing demands of technology-enabled creativity and assessment preparation influencing what it was that teachers valued, reconciliation was achieved in various ways, including the use of technology to

- enable more responsive teaching through apps that would provide automatic feedback,
- promote students' interest in content revision, and
- allow students to record their own explanations and acquisition of understanding.

It might well be noted that the school's valuing of creativity, and of learning to become effective learners, was more evident in the last of these three; and indeed when considering the use of the online quiz for content revision, it was unclear whether that use of technology was of material benefit. While the students evidently enjoyed the class, observations from the back of the room noted the prominence of the app's self-promotion, with the main part of the screen reserved for the Kahoot! logo, and with the answer options relegated to a narrow strip at the bottom of the screen (Figure 4.6). Since the students' devices did not display the answer options at all, it was doubtful whether all of the students at the back of the room could actually read the options they were selecting. In addition, the appropriateness of the messages on the students' devices was also questionable, with students subjected to exhortations such as "Pure Genius" when they had answered a question, irrespective of whether or not the answer was correct; and a red screen with comments such as "Trick Question?" when their answer proved to be wrong.

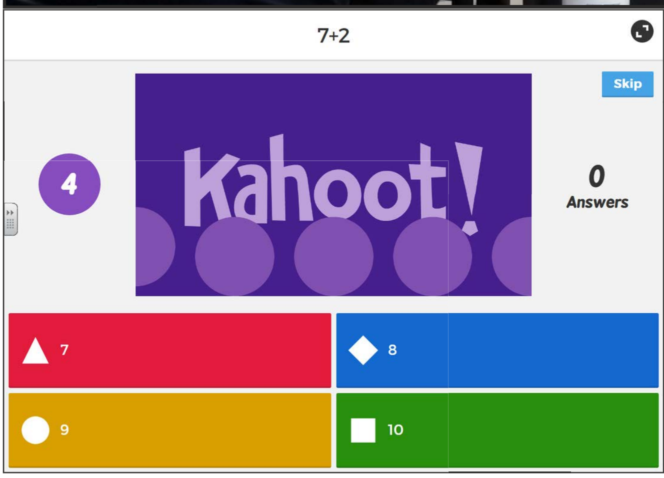


Figure 4.6. Classroom with television screen on which Kahoot! questions were displayed; and a sample Kahoot! screenshot. (https://mrsammonstechhelp.weebly.com/mrs-ammons-blog/kahootit)

> ## ➢ Research Question 2
>
> How do traditional mathematics assessments influence teacher perceptions of the effectiveness of teaching with student-centred mobile technologies?

As a Years 7 - 10 school, St Johns Wood maintained a cautious position regarding assessment, which evidently impacted upon its ability to justify radical pedagogical change. Despite the school's championing of creativity and resourcefulness, and its whole-scale adoption of standardised student-centred technology, there was a limit to how far it could reasonably skew its pedagogies and assessment practices. With an ultimate aim of producing students who were equipped to change schools at the end of Year 10, it was evident that the staff at St Johns Wood felt that they had an obligation to teach students how to be successful in Years 11 and 12. It was therefore the case that the school modelled attitudes that it expected students to encounter after they leave, attaching great importance to traditional summative examinations and actively teaching students to pass exams, with a perception that the ability to perform under examination conditions was a vital life skill, necessary for students to develop in order to give them the best chance of being able to follow their preferred paths.

In accommodating this combination of forward-thinking pedagogy and traditional summative assessment practices, St Johns Wood demonstrated the trade-offs inherent in education that must tread a fine line between idealism and conformity, whilst catering to the full spectrum of student abilities. Its solution has heretofore been to accept the supremacy of assessment in their charter, which to date has resulted in the use of technology as an adjunct to traditional teaching methods. While the maintenance of a learning journal was a concrete manifestation of the valuing of self-sufficient learning habits and creativity in mathematics, this was evidently a minor consideration when compared to the ability to demonstrate competence under examination conditions. With higher-achieving students

- that is, students who achieve at a higher level in mathematics assessments - singled out for their use of technology to self-teach, there was a clear inference that this practice was unusual, and would not be expected for the majority of the student population.

4.3. Case Study: Osterley High School

Located in metropolitan Sydney, Osterley High School is a co-educational government school of approximately 1000 students, with a partially selective student intake. At the time of the first interview (2016), it was mathematics teacher Elizabeth's first year with the school, having transferred from a small private school at the end of 2015; and during that year she taught two Year 7 classes, three Stage 5 classes including the bottom Year 9 and the second-top class in Year 10, and Year 11 General 2 (NESA, n.d.c). Observations were conducted the following year (2017) with a Year 11 General 2 class.

Elizabeth was a confident though self-deprecating user of technology, a skill that had been recognised in her short tenure at the school:

> Everyone's like going, "Oh you're so amazing with tech." And I'm like, I'm seriously not. (Elizabeth, OHS1 0:21:11)

With a considerable range of technology literacy in her staffroom, Elizabeth had become the de-facto expert from whom the rest of the staff would seek assistance with classroom technology. At the other end of the spectrum, Elizabeth said that there was also a highly experienced mathematics teacher who used "absolutely no technology" (Elizabeth, OHS1 0:18:34), to the point where he would continue to hand-write all of his material.

> He still hand-writes tests. So we still give out, to our Year 12, handwritten exams. Any exam that he does is handwritten. So, Year 12, he just handwrites it, very neatly, spacing, draws little Cartesian planes when he needs. (Elizabeth, OHS1 0:16:30)

Elizabeth felt that, for her colleague, the time to develop technology-rich pedagogies may have passed.

> It’s too late. He’s slightly older than me - I think he’s about 60. But I think - well where have we let him down, along his journey … [we] can’t just bring in a computer and say, here’s a computer, use it. (Elizabeth, OHS1 0:18:48)

However, Elizabeth believed that between them they had developed a mutually beneficial reciprocal arrangement, whereby she would help him with technology, and he would give her access to the worksheets that he had accumulated over the years.

> He has all these questions and all these sheets, like, years and years worth. He has an amazing collection of handwritten worksheets. That potentially could make quite an awesome book! … He’ll have six or seven different sheets on surface area … You just photocopy them into a little booklet, and it works great for lower-ability 5.1s [see NESA, n.d.b]. All the diagrams are there, and it says, this is what you do, and then you just do it. And you do it and you do it and you do it. And they can do it. They can actually sit down and do it. (Elizabeth, OHS1 0:17:07)

While Elizabeth’s students could use mobile devices in class, she found the school’s internet connectivity to be insufficient for the smooth running of real-time networked applications. As an example, when Elizabeth organised an activity through Kahoot!,

> I’ve got this huge lag time while everyone’s trying to get on, and invariably because 30 people all want to log on to the internet at once, it drains it, sort of? I don’t know. (Elizabeth, OHS1 0:38:53)

Given this restriction, Elizabeth’s employment of technology has tended to favour more asynchronous usage, and her adaptations to compensate for inadequate bandwidth demonstrated a considerable breadth of possibility for teachers to benefit from classroom technology, despite a lack of resources.

4.3.1. Flipped Learning with Powerpoint

While Elizabeth acknowledged that the use of Powerpoint and similar presentation software could be seen to be uninteresting for the purposes of discussing technology use in class, she contended that it was not the application itself but the way that it was used.

> Well it's the way that you use Powerpoint, too. You see, people think of Powerpoint as just conventional slides. But I've actually got, like, games within the Powerpoint where you've got, you know - the timers are all built in … or colour little cards that you have to select and wave. So yeah - it's not just copying down. (Elizabeth, OHS1 0:21:36)

In Elizabeth's case, Powerpoint also allowed her to manage absenteeism, to ensure that all of her students had access to the entire course irrespective of external commitments. She used a Surface laptop, annotating her lesson at the end of each period and putting it online for students who were unable to attend. During the lesson observation, Elizabeth used a Microsoft Word document in a similar way, except that it had also been printed into booklets for her students to fill out. Students therefore benefited from technology use, if "technology" was understood to include the ability to print booklets; and Elizabeth, in completing the document on her screen as she progressed through the course, effectively created course notes for any students who were not present. In addition, Elizabeth's students were provided with a complete roadmap of every lesson for the term, and at the beginning of each topic she would provide a list of all of the exercises that they would need to complete.

Elizabeth was also considering adding voice recordings to the lessons, but admitted that

> I haven't gotten that brave yet. It's not brave, it's - I haven't got the time to do that … but it's where I see it going, you know. (Elizabeth, OHS1 0:25:24)

Elizabeth acknowledged that it was difficult to know if the absent students had accessed the lessons, and so she made a point of checking the students' books to see if they showed signs of engagement with the content they had missed. She planned to automate this check by videoing her lessons and making them accessible through EdPuzzle, an online facility which would allow her to

> make sure the kids have watched it, because it tells you, and you can ask them questions as they're going through (Elizabeth, OHS1 0:27:03)

but in the meantime, the technology she used made it possible for her to assume that absent students were able to keep up - an assumption that she verified by following up with students who had been absent.

> I check my kids. The kids who are missing, I'll check their books the next lesson and make sure they've done the work ... So they know they'll be chased up on it. But then, they do it. (Elizabeth, OHS1 0:36:34)

She believed that her approach made a positive difference to the students' results.

> I think [the technology is] helping their engagement, which flows on to better marks. I don't think it directly goes better marks, I think that the kids know that I've put in effort, so they'll put in effort, and know that the expectation is high. They have to have - like if they miss a class it's all there. There's no excuse. So, nobody has big chunks of learning missing. (Elizabeth, OHS1 0:35:35)

4.3.2. Formative Assessment with Plickers

While content coverage was a significant driver for Elizabeth's use of Powerpoint, she also used the technology for formative assessment. Some of her games on Powerpoint were geared towards the acquisition of formative assessment data, including the games with the aforementioned coloured cards.

> The question will come up on the Powerpoint, and then they hold up - like the answer will be red, blue, yellow or green and they hold up whichever colour card they think it is. But then they all can see. So I mean I try and do it, OK on count of three, 1, 2 3, but then they all go and switch their cards around. (Elizabeth, OHS1 0:42:29)

With such difficulties in obtaining a true indication of her students' understanding, Elizabeth introduced Plickers, an application that includes a set of flashcards not unlike QR codes (Figure 4.7). Each student had a unique card that could be rotated to show four different multiple-choice answers.

> It gets around the problem of everybody looking - because I've done a lot of whiteboard work for that as well, you know where you get people to show you

Plickers card for Student 1, oriented to show:

Plickers card for Student 2, oriented to show:

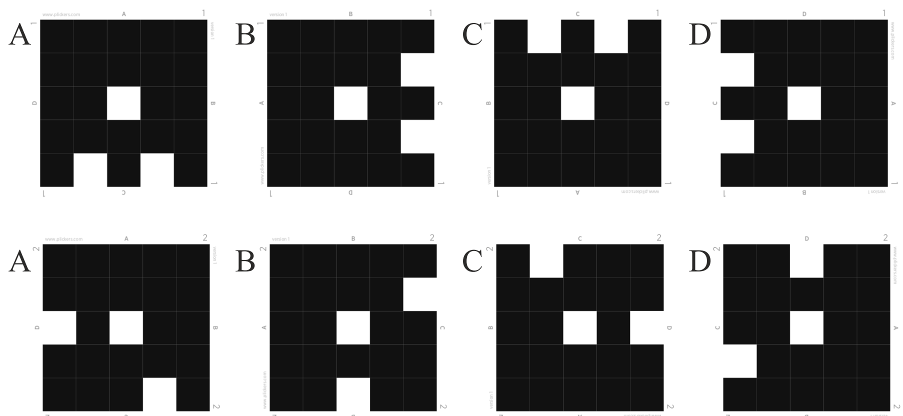


Figure 4.7. Plickers cards. (https://assets.plickers.com/plickers-cards/PlickersCards_2up.pdf)

> whiteboards. So it's sort of like whiteboards but it's whiteboards that, um, mean you don't know what answer everyone else is doing … It just gets away from the - I'm not going to say cheating, but you know it just allows kids to make a mistake. (Elizabeth, OHS1 0:39:22)

While Plickers and similar methods of formative assessment do use technology, Elizabeth found that they also allowed her to circumvent some of the issues with using technology in class. Aside from bandwidth issues, she found that

> it gets away with all the BYOD problems, you know the kids who don't have, can't afford, blah blah blah. It gets away with all your issues because if it - if the internet at school is down then I just go on to my 4G … And I just find they take it more serious than they do with Kahoot. Kahoots can get out of control. (Elizabeth, OHS1 0:43:13)

4.3.3. Rich Assessment Tasks

Osterley High School conducted four mathematics assessments per year, three of which were examinations, and the fourth being a project-based "rich task". Examples of such assessment tasks are included in Appendices A-9, A-10, A-11 and A-12.

At the time of the first interview, Elizabeth was working on updating an existing Year 7 assessment task, which originally required students to create a poster about the student's favourite number. Her idea was that students could be allowed to choose to create a digital product, and provide access to their work via a QR code.

> I just imagine this really lovely time when the parents come in, and had their phones, and could scan the QR codes and see what their child did, but could also

> see what other students did. They could get an idea of where kids can go with this. (Elizabeth, OHS1 0:45:27)

She noted, however, that despite the ostensibly creative nature of the project, students were not rewarded for their creativity; it simply was not valued in the marking scheme that Elizabeth had inherited from the previous version of the task.

> There's no marks in the rubric for creativity … It's all just, Have you got, is your number, have you identified your number as prime, and even … you know, cultural context, all that sort of stuff. (Elizabeth, OHS1 1:34:50)

Creativity also figured in the Year 8 assessment task, which required students to use a website to design a house according to some given mathematical parameters, such as land to house size ratio. Students would provide costings for building materials and solve the problem of accommodating guests for two years.

Elizabeth expressed some concerns regarding the comprehensibility of this assessment task, and was planning to do it herself so that she could understand what it was asking for.

> They were given - I don't really understand what's expected of those kids, from reading it. So I'm going to do the assessment task this weekend … I want to really spend some time deeply thinking about [it]. (Elizabeth, OHS1 0:53:40)

The reasonableness of the assessment tasks was an issue that Elizabeth thought could be better handled. Irrespective of the year level, from the Year 9 students' low-tech assessment task involving the construction and use of clinometers, to Year 10 financial spreadsheets and the Year 11 focus study on car ownership and blood alcohol, she felt that the assessment tasks were too onerous and required too much of a time commitment from her students.

> What's a reasonable maths effort, for students to be putting into an assessment task? Like is a whole day reasonable? … And do you want students spending eight hours on a Saturday, that's what a whole day is, or a Sunday, on that one assessment task? … You know that if you hammer them so much that the work becomes overwhelming, they're not going to get there. It's finding that sweet spot. And these assessment tasks, I don't believe, hit the sweet spot. (Elizabeth, OHS1 0:56:05)

Drawing largely upon her perception of the time commitment required to complete the rich tasks, Elizabeth was convinced that the students did not like this method of assessment.

> For all these groovy assessment tasks that we come up with, they don't want, in my experience. They will find - the good kids will find the silver lining. Like they will go, "OK, so the focus study was such an annoying assessment task," it took them so long, blah blah blah. "But I suppose one day we'll have to buy a car, so maybe it's good for that." … But if you said to them, "Would you prefer a test?" They'll say yes. (Elizabeth, OHS1 0:51:38)

4.3.4. Examination-based Assessment

Elizabeth's perspectives regarding the project-based assessment, and her assertion that students preferred examinations, was tempered by a revealing insight she had gained into her students' attitudes towards mathematics assessment. In Elizabeth's opinion, students preferred tests

> because it allows them to be lazy. Because they can go in, and fail the test, and it just reinforces the fact that they're useless at maths. And they can do it without having to do any study. (Elizabeth, OHS1 0:48:12)

Elizabeth's perception was that students would self-label, adopting a "fixed mindset" (Dweck & Leggett, 1998) regarding their mathematical aptitude, and having preconceived notions regarding their expected performance in a forthcoming examination. In particular, she believed that students in lower-ability classes effectively gave themselves permission to aim low.

> The kids in the low ability classes already have this assumption that they're really stupid at maths. They can't do it. OK. So then they come in to a test, and they're usually not prepared, because a lot of the reason why they are stupid at maths and can't do it is because they actually haven't bothered to really apply themselves to it, to really take that time out and think deeply about the problem, that they're not that kind of kid, they're kind of scatty, and you know. And then … they don't do well on the test, but it's an hour of pain. (Elizabeth, OHS1 0:48:37)

This "hour of pain" contrasted with the many hours of work that would be expected for a project-based assessment. It was perhaps curious that the lower-ability students would feel obliged to put effort in to the project task, given their perceptions of their own self-worth; and indeed, Elizabeth was clear regarding these students' attitudes towards their success or lack thereof:

> I thought that kids would prefer to do an assessment task, where they could be successful. But they actually hate the fact they have to spend a lot more time … They couldn't care less [about the result]. Because they already think they're stuffed at maths. (Elizabeth, OHS1 0:49:20)

This being the case, it was surprising that Elizabeth felt that her higher-ability students appeared to maintain a similar perspective regarding time and effort, and so they, too, would prefer an examination.

> They know they'll do well on the test … Walk in, breeze through the test, they get 70% or 80%, whatever they get, and they're happy (Elizabeth, OHS1 0:49:42)

incidentally evincing a somewhat blasé disposition towards the finer-grained aspects of marks and relative ranking. Indeed, in Elizabeth's opinion, this preference for minimal effort carried through into Year 11, when the results would begin to be significant for the students' Higher School Certificate:

> My Year 11 Generals, they get to do a big investigative project … and they much prefer tests, because it is an hour, or an hour and a half. (Elizabeth, OHS1 0:51:06)

4.3.5. Work Ethic

Elizabeth's observation that examinations allowed students to be "lazy" led to her doubting the advisability of tests as an assessment mechanism; and, despite having reservations regarding the tedious nature of the school's project-based assessment tasks, she firmly believed that "we really need to move away from tests" (Elizabeth, OHS1 0:48:08). Indeed, Elizabeth's attitudes toward both assessment methods were consistent with her belief in student engagement and application:

> if they apply themselves and do good work - regular, minimal amounts of work … they're going to get there. (Elizabeth, OHS1 0:57:43)

Work ethic was a major recurring theme for Elizabeth. She strongly believed that her students could all succeed, and suggested that failures were largely attributable to disengagement or artificial constraints. Of her lower-ability Year 9 class, she noted that

> they fail the test because they're not supported to pass it, not because they can't pass it … They're not allowed to take notes in. They've got to remember all the

> formulas - I mean, they don't want to do that … I want them to experience success, so I want them to be able to have their formulas, written, you know, someone to help them prepare that formula sheet, so they learn how to study. Make them do work. You know. But they just - they're allowed to just come in and fail. Whereas I wouldn't allow that. (Elizabeth, OHS1 1:32:01)

Given a lack of power to change the school's assessments, Elizabeth chose to institute consequences for failure for the students in her classes, in order to deter them from choosing to simply "roll up and fail" (Elizabeth, OHS1 0:50:24).

> Your work ethic here gets rewarded, but you don't have to do anything. And you fail the exam - what happens? So now, with some of my lower ability classes, if they fail the exam they have to resubmit it as an assignment. OK. So you can't just fail it. (Elizabeth, OHS1 1:30:50)

She would then follow up with the students to ensure that the requisite learning had actually occurred:

> I sit down and I'll go through it, the ones that they've got. "How did you do it this time? What did you do differently to what you did in the exam?" So that they can't just [ask someone else to do the exam for them]. (Elizabeth, OHS1 1:31:41)

4.3.6. Teaching for Understanding

Elizabeth's position regarding the importance of doing regular work, and the value of constant study habits, was supported by her beliefs regarding the way in which mathematical understanding develops. Her preference was to teach and revise in tandem, so that the students would be learning new material whilst being exposed to concepts that had been introduced at an earlier stage.

> Mastery comes from doing it over time, in different ways. So I prefer to do a little - a few questions, often at the beginning of a lesson, that cover all the content that they've already learnt, and then teach something new, but you don't have to master that in that lesson because we keep going over it and over it and over it … Some of the other teachers will just concentrate on that and if they can't do it, they can't do it. (Elizabeth, OHS1 0:00:15)

Elizabeth claimed that her choice to develop her students' understanding and mastery through constant revision had served her students well. She contrasted this method against a situation in which she had chosen to deliberately teach for understanding. The lesson was intended to teach the formula for the area of a circle; and in an attempt to promote understanding, Elizabeth demonstrated the derivation of this formula using some very basic calculus concepts, as shown in Figure 4.8.

Elizabeth recalled the satisfaction of teaching the proof, and finding that her students were able to appreciate its significance:

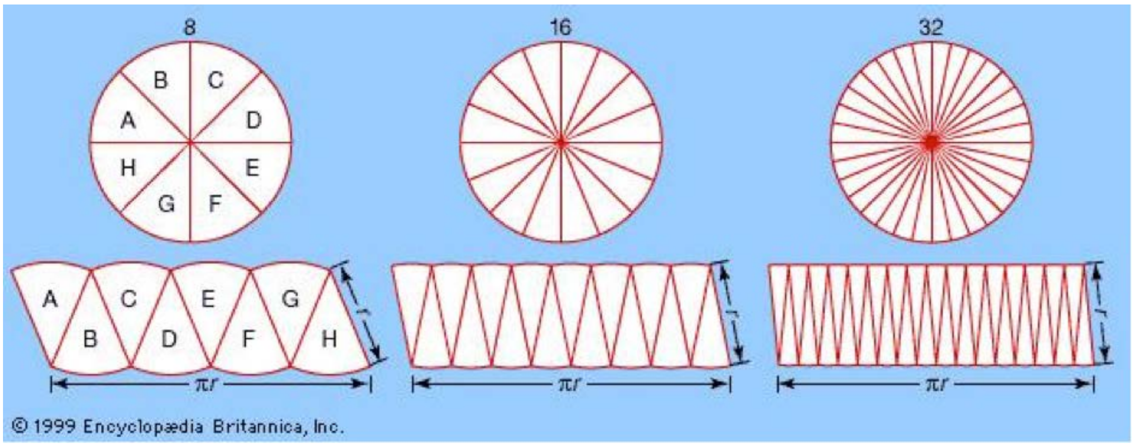


Figure 4.8. Derivation of the area of a circle. (Encyclopaedia Brittanica, 1999)

> So I'm going, "Isn't this amazing?", and they're all like, "Yes!" Finally got some of the really limited ones, they get it, and I found one of those things [a teaching aid consisting of a circle cut up into thin sectors], oh it was all so good. Then, I had them doing area of a rectangle equals πr^2. Because they remembered the rectangle, not the circle it had come from! (Elizabeth, OHS1 1:21:10)

With colleagues advising her to just

> tell them what to do. That's all they want. This formula … like that. You're trying to get them to understand it, they'll never (Elizabeth, OHS1 1:21:36),

Elizabeth was forced to confront the dilemma of whether it was meaningful to simply teach to the test.

> If they can learn a procedure, get some marks in an exam, because that's how they're going to be ranked. It's so terrible, isn't it. … Am I teaching this student holistically for their understanding, or am I teaching this student to get one more mark, so it ranks them up one more rank? (Elizabeth, OHS1 1:25:40)

The same issue was, however, possibly less ambiguous when discussing pedagogies for senior students. As an example, for Year 11 statistics,

> You don't need to teach sample, but it's in all the textbooks. So would you - do you add that layer of knowledge? or do you just concentrate on the - what is it? What are you teaching? The test? or are you teaching like - in Year 11 and 12, in the end, you really are teaching the test. (Elizabeth, OHS1 0:03:03)

It was apparent that Elizabeth valued the development of understanding, but from a pragmatic viewpoint there was understanding that was valued, and understanding that was not examinable. In the case of the circle area formula, the proof was deemed unnecessary, and was therefore unimportant - despite any potential for forming foundations for further mathematical insights, such as (for example, in this case) the mutability of shapes for the purposes of area calculations.

4.3.7. Valuing Creativity in Student Mathematics

The favouring of examinable outcomes was also relatable to a perception that student creativity would be of lesser importance. Elizabeth openly admitted to struggling with her thoughts regarding creativity in student mathematics, and required some prompting to realise that not only did she personally value a more creative approach to mathematical thinking, but that she actively encouraged it in her teaching.

> OK I want to be doing that, but am I? Yeah. Am I valuing creativity? When I'm just asking them questions in class and seeing how they're going - not really. I'm being creative, but the way I'm asking them, am I valuing their responses in a creative way? (Elizabeth, OHS1 1:36:14)

However, following some discussion of creative problem solving methods, Elizabeth realised that she had, in a recent lesson, taught in a way that demonstrated the value she placed on creative problem solving.

> In the trig lesson the other day - where … because they were solving things by trig, they were - I knew they would solve it by trig, but it was two much easier ways to solve it. So once they'd solved it, I said, "Yeah, how'd you solve it?" And the majority of the class had all done it the hard way. Well not the hard way, but the long way. I said, "Can you think of other ways to solve it?" … So that was kind of cool. (Elizabeth, OHS1 1:38:55)

Similarly, she did activities such as “this is the answer - come up with five questions” (Elizabeth, OHS1 1:39:35), particularly with the younger students, and she described the joy of watching her students discover number patterns and make connections with the mathematics they knew.

However, she also described the experience of teaching one particular Year 10 student, whose creative thinking was devalued in favour of conformity and fluency.

> I have this one student in 10.2 [Year 10, 5.2 (NESA, n.d.b)], who can never ever ever finish a test in an hour, but what he does, he gets 90% right. So he’s getting marks of 60%, right ... So I speak to the learning support team. It’s like, if he could have an extra half an hour, he’d be able to demonstrate his full thing. (Elizabeth, OHS1 1:41:40)

Elizabeth contended that, despite the student’s examination results, he clearly had developed a deep understanding of the content of the course, and had shown this through the creative way in which he took notes.

> So I’ll correct his book, and there’s, instead of it being, like, the equation of a line is $y = mx + b$, and this is the gradient or whatever, he’ll have this whole diatribe about what’s it like to be a line. This whole conversation about, what is it like to be a line, and how’s it feel to be a gradient, and would you like it if you were a negative gradient or not … I mean he doesn’t do that in the exams, but he’s got these really interesting books. Really interesting that he doesn’t - he never just copies what’s being said. He’s always thinking about it, even if it’s a bit weird. (Elizabeth, OHS1 1:43:03)

Elizabeth demonstrated the student’s slowness of speech - “everything is just done at that pace!” (Elizabeth, OHS1 1:42:19) - and argued that he just needed a bit more time to demonstrate his true ability; but was given to understand that, for his HSC, the student would be permitted no more than a five minute break as a concession to any diagnosed condition.

> But I just think, oh it would be sad … that that result was always going to look like he doesn't understand as much as he does. … They're going, "Oh he can't get anything, you know, like, he's doing well enough. He's in 10.2." I'm like, "He's not doing his potential. I don't care how well enough he's doing, he's not doing - he's not showing you what he can do. Doesn't matter that he's achieving well, he's not achieving as well as he can." (Elizabeth, OHS1 1:44:20)

4.3.8. The Sweet Spot: Balancing Work and Extracurricular Interests

> ➢ **Research Question 1**
>
> What do secondary mathematics teachers value in student learning with mobile technologies?

With an evident belief in her students' ability to improve with regular work, it was apparent that Elizabeth's pedagogy valued work ethic above all other factors. This disposition was made clear to her students through Elizabeth's own work ethic, and enforced through constant checking. It was also evident, however, that Elizabeth did not agree with a burdensome work schedule; she valued regular work, but not in such quantities that it would be onerous for the students, or interfere with their pursuit of other interests.

Elizabeth's lesson planning demonstrated an appreciation that the development of understanding and mastery would be most effectively achieved over time. Her belief in the increased effectiveness of learning with spaced practice is supported by studies such as those described by Balota et al. (2007), which found that spaced repetition was consistently superior for the development of longer-term memories. In particular, Rohrer and Taylor's (2006) experiment indicated that distributed mathematics practice was significantly more effective for performance in assessment tasks that were conducted following the elapse of greater periods of time. Additionally, Rohrer and Taylor's (2007) experiment on mixed practice also validated the effectiveness of Elizabeth's standard lesson procedure, whereby she would begin her classes with revision questions from different topics. It was apparent that, irrespective of Elizabeth's technology use, her pedagogy drew upon a sound theoretical base for improved retention. The technology enhanced this by ensuring that her students had no excuses for not keeping up with the rest of the class.

Technology use permeated multiple facets of Elizabeth's practice, providing her with access to game-like pedagogies, formative assessment and flipped learning, as well as allowing her to reciprocate in collegial exchanges. Given the issues she described regarding the inadequacy of the school's internet bandwidth, it was unsurprising that student-centred use of technology in the classroom was fairly limited, but Elizabeth was largely able to compensate for this through her choice of applications - essentially giving her students printed cards and printed booklets that could rival the effectiveness of some classroom-based digital technologies. The other major aspects of student-centred technology use were the flipped learning and the completion of the "rich task" assessments, both of which relied on students' asynchronous engagement with technology in their own time.

> ➢ **Research Question 3**
>
> What do mathematics teachers perceive to be the characteristics of assessment methods that enable and encourage the use of mobile technologies?

Elizabeth's situation was particularly significant for the purposes of this research because it actively belied the generally-unquestioned idea that students care about their marks. Instead, in Osterley High School we were privy to a curious phenomenon, as noted by the teacher, whereby students were apparently indifferent to their examination results, and yet felt obliged to make an effort for other types of assessment - whether this be project-based assessment or routine book checks. We could at this point speculate that the circumstance may share some similarities with the field experiments described by Fryer (2011, p. 1792), in which the qualitative data demonstrated that students did not know what tangible steps they should take to improve their results. It is possible, for example, that the rich task - being a project that the student could discuss with parents and peers - was achievable, as was the bookwork. However, methods for studying for an examination were perhaps less widely understood.

This interpretation of the anomaly appears to fit when we consider that Elizabeth was actively trying to gain special consideration for her lower-ability Year 9 students, so that they could be supported to create a set of study notes and then be allowed to use them during the examination. Indeed, the artificially restrictive nature of the examination was flagged as an issue in a number of scenarios, mainly with regard to influencing pedagogical choice, but also in individual circumstances such as that of the student who needed more time to be able to demonstrate his full potential. The examination in its traditional form necessarily assesses a confluence of a particular set of skills, and, just as there are instances of skills that are not examinable, so there are skills that are necessary in order to demonstrate competence under examination conditions; and results would be expected to suffer when any one of those skills is lacking.

Elizabeth's unequivocal statements regarding Osterley High School students' preference for the short test may also be more understandable when we consider that Osterley is a selective school. Students are chosen, not for academic ability, but for talents in other areas; and thus it would be unsurprising for the students' involvement in extra-curricular activities to interfere with their commitment to studies in core subject areas. While Elizabeth did explain that

> it is an expectation from the school that students who do those sorts of extra activities, don't do it at the expense of their progress in their other subjects; they must keep that up (Elizabeth, OHS1 0:37:09),

it would be reasonable to infer that the general school culture would reflect something of this extra-curricular focus; and given a prevailing sense that there were other areas in which they could shine, there may be a greater overall potential for the students to feel that assessment results in mathematics were of lesser importance.

It is notable that, although the Osterley student culture appeared to favour a more relaxed view of academic priorities, Elizabeth was able to employ digital technologies to impress her own values upon her classes. Her high level of proficiency with technology, and a confidence in her own ability to manage the investiture of new applications, gave Elizabeth the ability to use the technology as a tool which could help to track and enforce the standards that she wanted her students to maintain.

With her insights into Osterley High School's mathematics assessments, Elizabeth's observations raise questions regarding the aptness of each assessment mechanism, and tend to suggest that in each case there are undesirable effects. However, it is equally clear that Elizabeth appreciated the difficulty of "finding that sweet spot" - the creation of a fair and reasonable assessment task that is not overly onerous, and allows students to demonstrate their learning, whilst giving them every chance to succeed.

4.4. Case Study: Bermondsey College

Philip was a mathematics teacher with Bermondsey College, a girls' private school located in an affluent part of Sydney. At the time of the first interview (2016), he had a part-time teaching load which included some junior classes, as well as all of the Year 11 and 12 mathematics classes for students aiming to complete the International Baccalaureate (IB). Observations were conducted in the following year with his before-school tutoring group, Year 9 5.2 class (a medium level class - see NESA, n.d.b), Year 11 IB Standard, and Year 12 IB Standard (IBO, n.d.d).

Year 7 students at Bermondsey College were required to have iPads for school use, but Philip noted that the students tended to exchange this for a laptop computer as they progressed through their schooling, and their choice of device often reflected the privileged nature of the demographic catered to by the school. In Philip's junior classes, the technology was used to provide students with access to electronic textbooks that were "all just PDF documents" (Philip, BC1 0:03:51), as well as access to some mathematics-focused interactive activities, such as Desmos and Geogebra.

Philip acknowledged that technology-rich lessons required considerably more effort to set up and run successfully, noting that

> as soon as you introduce technology into a classroom with young kids, everything that could go wrong, probably will go wrong (Philip, BC1 0:06:29)

and so he explicitly checked all of the activities before giving them to the students:

> I literally have to test it on an iPad myself. I press on that link, will it open up the app, and will it then be able to be worked, used, effectively? It seems simple, doesn't always work. (Philip, BC1 0:07:18)

> ➢ **Research Question 1**
>
> What do secondary mathematics teachers value in student learning with mobile technologies?

Given the attendant difficulties, Philip's classroom technology use was very considered, and driven largely by his judgement regarding its relative potential for improving student learning. It was apparent that, from Philip's perspective, improved student learning equated to the development of mathematical understanding. His attitude reflected a belief in the importance of establishing firm foundations, a philosophical position that led him to teach content from first principles, despite appreciating that the students would not require that depth of understanding for assessment purposes:

> I wouldn't cut it down to just the bare bones - no, no, no. A lot of the stuff like even that Year 11 class I'm currently doing, we always go and understand how all those proofs work. Like sine rule, cosine rule, binomial theorems … you do want to do that because it then builds foundation of their understanding.
>
> Because otherwise, without that, you'd just basically be becoming a trained monkey, just, like, processing numbers. And that's dangerous. (Philip, BC1 0:20:32)

With this perspective, Philip was able to justify the use of technology when it was clear that it helped students to understand mathematical concepts.

> Year 8 last year, I can remember when I was teaching them all of the different properties of quadrilaterals. We would send them off to a Geogebra site which had all these little interactives that they could manipulate. So they would manipulate them on their iPads and then write down their results, pen and paper. (Philip, BC1 0:04:10)

In this instance, Philip chose to use Geogebra as a proxy for concrete materials. This was partly because Bermondsey College did not have designated mathematics classrooms, and so rather than obliging the teacher to transport mathematics manipulatives around the school, students' iPads offered a convenient alternative mode of lesson delivery. The key, however, lay in Philip's own appreciation that interaction with the shapes was instrumental for developing student understanding:

> Some of the concepts are really hard for students to understand … So when you can give them something that they can actually interact with, and touch and play with and fiddle around with, and then discover it for themselves, instead of just being told, you know, the properties of a rhombus are this, right, they actually have to work it out - it does help. It does help a lot. (Philip, BC1 0:04:59)

However, he also considered other factors when planning for technology use:

> It depends on which level of class you're teaching. That was with a higher level ability class. I wouldn't do the same with a lower ability class, because using lots of tech with low ability students isn't really great. It's better to actually have concrete devices. Like, literally giving them shapes, and make them cut out nets. (Philip, BC1 0:07:52)

Philip evinced a belief that the abstract representation of mathematical concepts through the use of technology was less suitable for lower-ability students. He offered an example to demonstrate the inadequacy of a flat-screen representation:

> They struggle with abstract, right … Classic example, I sort of put it up on the board with the current Year 9 class, a picture of a rectangular prism, right, so it's on a 2-dimensional plane, and it's got all the cubes, right, each cube's one cube, right.

> And you say to the kids, “How many cubes make up this rectangular prism?” And they literally count the ones they can see. And they go, “17.” “What about the ones at the back that you can’t see?” “What ones?” (Philip, BC1 0:08:27)

However, the two-dimensional nature of the iPad was apparently not the only gating factor for Philip’s use of mobile technology with lower-ability students. Despite the expectation that all students would have iPads, Philip made a deliberate choice to use a low-tech alternative for his lower-ability class.

> One of the things I have done with that class, is just a lot of drill, right, which a lot of people think - that’s old school. That doesn’t work. Oh yeah, it worked. Oh, God, it worked. And it’s real old school stuff. I get little - you know, whiteboards, about this size, give them a pen. No technology. And then I use the technology. So you put up on the smartboard, an image of whatever. Whatever question. And you say, right - write down the answer. And then they all have to write down the answer, and then they have to show me … And they love it. They absolutely love it. And, you know, they get - instant gratification. (Philip, BC1 0:54:23)

4.4.1. Technology Use in Examinations

Bermondsey College offers students the choice to undertake the International Baccalaureate’s Diploma Programme (IBO, n.d.c and n.d.d) as an alternative to the NSW Higher School Certificate. As the teacher responsible for Bermondsey College’s IB Standard mathematics classes, Philip’s work was guided by an assessment regime that differs in a number of respects from the HSC. There are two aspects of this assessment that are particularly notable for the discussion at hand.

The first is the mandated use of graphing display calculators. These offer much the same functionality as mobile devices running apps such as Desmos, with the essential difference being their inherent inability to support further technological affordances. IB students are expected to have graphing display calculators in mathematics examinations, leading to them working with questions that exhibit different characteristics:

> Let's say what we're doing at the moment - well we're trying to solve trig equations. You can solve trig equations on a graphing display calculator with ease, right, because you just plot the trig equation, plot what it's equal to … you just plot the whole thing and solve it, and you can set the domain, and you can see where the points of intersection are, and it's very simple and straightforward. To do it by hand is a different exercise altogether. (Philip, BC1 0:11:47)

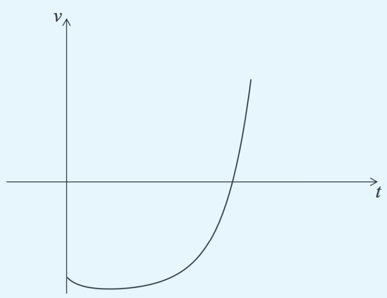
The ease with which equations might be solved using a graphing display calculator necessarily modified the nature of the mathematics that students were expected to comprehend (Figure 4.9). Philip explained that, while he taught the students how to solve the problems both with and without the graphing display calculator,

6. [Maximum mark: 6]

The velocity $v\,\mathrm{m\,s}^{-1}$ of a particle after t seconds is given by

$$v(t) = (0.3t + 0.1)^t - 4\text{, for } 0 \le t \le 5\text{.}$$

The following diagram shows the graph of v.



(a) Find the value of t when the particle is at rest. [3]

(b) Find the value of t when the acceleration of the particle is 0. [3]

Markscheme

a. recognizing particle at rest when v = 0 ***(M1)***

eg $(0.3t + 0.1)^t - 4 = 0$, x-intercept on graph of v

t = 4.27631

t = 4.28 (seconds) ***A2 N3***

[3 marks]

b. valid approach to find t when a is 0 ***(M1)***

eg $v'(t) = 0$, v minimum

t = 1.19236

t = 1.19 (seconds) ***A2 N3***

[3 marks]

Total [6 marks]

Figure 4.9. Question requiring graphics calculator from IB mathematics paper, with marking scheme.

> using that sort of technology in those classes is a completely different proposition because it then becomes an integral part of the course. You have to be able to use that calculator … [It] has to be taught. It is like imperative. If it's not taught, your kids will not be able to answer questions. At all. (Philip, BC1 0:12:30)

Philip's disposition regarding the use of graphing display calculators was evident in his attitude towards the Higher School Certificate course, which

> are still set 30 years ago. And based on, you know, a time when log tables had just been superseded. By calculators.
>
> … The syllabus that was set for my leaving certificate is still in place today. So, notwithstanding the advent of 30+ years, there doesn't seem to be any change in the syllabus or desire to move with modern technology. Which is really quite bizarre. (Philip, BC1 0:13:23)

While Philip clearly appreciated the need to update the mathematics course to take technological advances into account, his attitude towards mobile technology in examinations was more circumspect. While he criticised the artificial restrictions placed on students in examination conditions:

> The reality is, if you're going to go off and do further studies in mathematics, you're going to be able to use whatever you can get your hands on. … They put in these artificial restrictions on what they can and can't use. It's just the rules, but not reality. It's test reality (Philip, BC1 0:15:38),

he also acknowledged the potential for students to procure unauthorised assistance if there was no technology restriction:

> The only problem is [if] they can just send a message to someone else who knows how to answer the question. Then that - it defeats the purpose. … I don't think you'd get anything other than searching skill, or their network of friends who can answer questions, or their ability to use Wolfram Alpha. (Philip, BC1 0:16:22)

To counteract this tendency, Philip speculated that perhaps a different style of question would be required, offering an example that shared some of the characteristics of Fermi problems (Department of Education, Victoria, 2007):

> Here's a picture of a water tank. OK. Work out the volume of it, and I'll give you no dimensions.
>
> … You couldn't give some labelled, like fully detailed piece of information that they'd then just have to know the mechanical process of solving. The questions would become completely different. (Philip, BC1 0:17:33)

However, Philip also felt that such questions might be overly difficult for some students, and so they might not be appropriate for assessment purposes:

> You've got to set it at a level what they can actually achieve. There's no point in sort of saying to someone, go and solve something that's really difficult to do. (Philip, BC1 0:18:48)

This perspective regarding the ways in which examination questions might need to change in order to compensate for the technology, was particularly intriguing given that Philip taught the IB course, which permits a particular level of technological affordance in its examinations. It was evident that, in Philip's view, the level of sophistication expected of students would need to increase commensurate with the sophistication of the technologies that were permitted under examination conditions.

4.4.2. Project-Based Assessment

The second notable aspect of the IB mathematics assessment is its inclusion of a compulsory written report, worth 20% of the student's grade, that is not produced under examination conditions. At Bermondsey College, this method of assessment was particularly novel since, for Years 7-10, they have reverted to assessment exclusively through examinations:

> We used to have sort of some assignment where they hand things in, and we found that typically that was either done exceptionally well, probably by someone else, or very poorly. So it didn't really actually give us a good indication about what the student actually knew … because all you'd get back was something the parent had done, or some tutor had done, or something else. (Philip, BC1 0:24:45)

Philip's view was that the teachers at Bermondsey College considered the examination-only assessment regime to be fairer, because the students must do it under supervision. He noted that while it may not be "the best type of assessment",

> it's the best that we can do, with the parameters that we've got. (Philip, BC1 0:25:20)

The IB's written report departs from this regime, requiring students to produce a 10 - 15 page mathematical investigation on a topic of their choice, which is then marked according to a detailed rubric that is known to the students in advance (see Appendices A-13, A-14 and A-15 for sample pages from a report written by one of Philip's students). For this report, students are

> allowed to use anything … Can they go and talk to people, can they use the Internet? Yep. Yep. And they're encouraged to. They're encouraged to use technology. (Philip, BC1 0:27:17)

Philip considered this report to be "a brilliant idea - a really good way to actually develop skills that they need to develop" (Philip, BC1 0:26:16), particularly as "it builds skills that you need when you finish school and go into university" (Philip, BC1 0:28:06). As such, he appeared to view this particular assessment task first and foremost as a learning opportunity. He maintained a positive perspective regarding its merits, despite Bermondsey College's experiences with the doubtful provenance of assignments from Year 7-10 students:

> If they get someone else to do it, then obviously it's a missed opportunity for them to actually develop those skills (Philip, BC1 0:28:17),

and while students were required to sign an affidavit to confirm that the assignment was their own work, Philip did note that

> there have been quite a number of instances where people actually paid for people to write these reports for them … People cheat. It's human nature, right. (Philip, BC1 0:28:49)

Philip brought multiple perspectives to discussions about the IB assessment. At the time of the interview, his own daughter was an IB candidate (Appendix A-16) - a situation with consequent potential dilemmas for Philip's own personal and professional practice. It was apparent, however, that he had set clear boundaries in his own mind regarding the level of help that was acceptable:

> I'm in this situation, I've got my daughter who is doing this course, the IB, a maths teacher, she's doing maths, she's going to write a report. Do you think I'm not going to help her? You know - I'm not saying she's not going to do her own work. She's going to do her own work, but I'm going to ensure that she addresses all of the issues that need to be addressed.

> … You get someone to actually write your whole report, and you have no involvement in it, yeah that's cheating. That's just outright cheating. And I'm sure that does happen. (Philip, BC1 0:29:46)

Notwithstanding these issues of integrity, Philip maintained that the report was both beneficial for learning and appropriate for assessment. He also, however, indicated that he believed that it was more suited to motivated students; and while the IB may merely be an alternative syllabus with its own assessment regime, it is designed to appeal to an exclusive cohort, with explicit built-in failure points for students who do not achieve to a particular standard. By withholding the IB qualification from students who are unable to perform to a satisfactory standard in three different higher-level subjects, it is clear that the IB is not only deliberately non-inclusive but actively seeks to maintain its status as a niche product.

It is therefore plausible that Philip's own certainty regarding the benefits of the IB assessment model might be partly attributable to the kind of student who could successfully attempt the IB (IBO, n.d.b). Since the IB actively discourages participation by lower-ability students, it may be that the students who choose to attempt the IB personally have higher opinions of their own academic self-worth and so are more likely to be self-reliant when producing a written assignment. The weighting of the report is also significant - 20% of the final mark is not such a large amount that it would skew the results for a student who could not perform competently for the remaining 80%; and yet not so little that the quality of the report is immaterial.

4.4.3. Tertiary Entrance Ranking

The IB assessment offers a further complication in that it maps directly to university admission through a formula determined by the Australasian Conference of Tertiary Admissions Centres [ACTAC]. To inform this discussion, we shall begin by considering the purpose of the Australian Tertiary Admission Rank (ATAR), a number that is calculated for students matriculating in NSW, ACT, Victoria, Queensland and Western Australia.

> The ATAR is a rank, not a mark.
>
> It is a number between 0.00 and 99.95 and indicates a student's position relative to all the students who started high school with them in Year 7. So, an ATAR of 80.00 means that you are 20 per cent from the top of your Year 7 group, not your Year 12 group. (UAC, 2016b)

Given that the ATAR is a rank, it is necessarily competitive. It is impossible for every student to be given an ATAR of 99.95, irrespective of how well they all perform in their matriculation examinations. However, this restriction does not apply to the IB, which offers students ranking that is comparable to the ATAR for the purposes of university admission:

> Your UAC rank is assigned based on your overall score out of 45 (as reported on your official academic transcript) per the table below [see Table 4.1]. For tertiary entrance purposes in all Australian states and territories (except South Australia, the Northern Territory and Tasmania), this rank is comparable with the ATAR. (UAC, 2016a)

The ATAR equivalence of these IB scores is defended on the basis of IB students' subsequent first year university achievement (ACTAC, 2016). It is notable, however, that the IB offers an unlimited number of perfect scores, in combination with a transparent assessment procedure:

> [The IB] have, on all of their past papers, unlike the Higher School Certificate where they've got this big secret bloody black box and they don't want to disclose how they mark it because basically they're making it up as they go - that doesn't apply to the IB. They - After they give out the exams, publish them to all the schools who have this course in their schools, they also provide the marking scheme. And it's very specific, how the marks are allocated. (Philip, BC1 1:34:10)

Philip noted that the IB score conversion had served his students well, with an impressive percentage

Table 4.1. IB scores and equivalent UAC ranks (ATARs) for 2016 and 2018.

Passing Score	**2016 Rank** (UAC, 2016a)	**2018 Rank** (IB Schools Australasia, 2018)
45	99.95	99.95
44	99.85	99.85
43	99.70	99.70
42	99.45	99.40
41	98.90	98.80
40	98.30	98.25
39	97.60	97.50
38	96.80	96.70
37	95.90	95.75
36	94.60	94.50
35	93.45	93.30
34	92.30	92.10
33	90.95	90.65
32	89.30	88.95
31	87.40	87.10
30	84.70	84.40
29	82.30	81.90
28	80.30	79.90
27	78.15	77.65
26	75.70	75.15
25	72.70	72.10
24	69.30	68.70

of students achieving perfect IB scores (and thus perfect tertiary admission scores) within the last two years. He likened the assessment model to the university system, with coarse granularity for marks:

> If you think about how universities assessed your grade, right, when you're undergraduate. You either get Pass, Credit, Distinction or High Distinction. That's what it's like. That's the best thing, because each course is marked out of 7. If you are at all a competent student … you'll get 7. And to get that in courses like the studies we're doing, you need to get 80% and above. … Like doing seven subjects at university, and getting High Distinctions in all of them. It's achievable. (Philip, BC1 1:37:30)

4.4.4. IB Mathematics and Valued Learning

The IB mathematics assessment model therefore offers a number of notable perspectives for how assessment might be manipulated for different pedagogical agendas. To summarise, IB mathematics differs from the NSW Higher School Certificate in a number of respects:

- The use of graphing calculators
- The inclusion of a centrally mandated written report comprising 20% of the final mark
- Explicit and transparent marking schemes
- Coarse granularity of scores (maximum score is 7/7, equivalent to a final mark of about 80%)

In addition, the IB diploma programme exhibits the following characteristics:

- Mandatory subject selections, including a foreign language and three higher-level subjects
- The threat of failure to matriculate if marks are unsatisfactory
- The promise of favourable score conversions to tertiary entrance ranks if marks are sufficiently high.

In combination, the IB assessment model bears remarkable similarities to university assessment. It is therefore unsurprising that there is a strong correlation between IB achievement and achievement in first year university, upon which the model used to compute the UAC score-to-rank conversions is based. However, given that the IB is not currently offered in any government school:

> No. Never. Because we'd be basically saying, we don't think the government's own, you know, approved and developed course is the best one. Some of them have tried. (Philip, BC1 1:38:50)

there is the inevitable perception that the IB is only offered to a privileged few; and the score-to-rank conversions, while potentially statistically defensible, give the appearance of favourable treatment. Indeed, it is unclear whether the IB course's promotion of students' university readiness confounds the conversion process, given that the IB students have had more opportunities to develop the skills valued at university, and as such may carry an advantage into first year university assessments.

The IB diploma is also particularly notable for its ability to transcend the values imposed by the NSW Higher School Certificate. It demonstrates the effect of offering an alternative assessment regime that results in a recognised and equally valid qualification - but, perhaps more pertinently, it is an assessment regime that aligns well with what is valued for the student's further education. This was evident in Philip's perspectives regarding the written report component:

> It doesn't make any difference, that I don't know trig equations any more. I will never use them. Ever, in my life. Whereas the skills that's writing a report, I will use for the rest of my life. … We all write reports. We all communicate. (Philip, BC1 1:15:31)

Philip made it clear that these skills were what he considered to be valuable learning, so much so that he chose to move his own daughter to a different high school so that she would have the opportunity to attempt the IB.

> I seriously believe that those skills that they develop by doing those internal assessment tasks are so valuable, compared to just doing coursework and exams and things like for the Higher School Certificate, that we changed schools. Because I think they really do develop skills that you still need to have at university and beyond. (Philip, BC1 1:14:26)

In making a point of including a written report in the mathematics assessment, the IB sends a clear signal regarding what it considers to be valued mathematical learning. The report, worth 20 marks in total, is accompanied by an explicit marking rubric:

> You've obviously got to be able to understand what maths is in that document, and do it all correctly. But that's only part of the assessment criteria, right. So, you know, out of the 20 marks in the standard I-level report, the mathematical processes that you have to demonstrate in that assessment task is only 6 marks out of 20. That's how they value it. So the other 14 marks is all about, how have you communicated, how have you addressed validity, how have you addressed personal engagement - you know - made this an interesting report. And these are all skills that - these are not - these are not maths skills. What we would typically call maths skills, but, yeah, it's still maths, related to maths. (Philip, BC1 1:16:14)

As such, the IB mathematics written report component makes the teaching of these alternative mathematical skills both mandatory and worthwhile. It demonstrates potential for the assessment of some of the 6 C's of Education (Fullan, 2013) in secondary school mathematics, with particular emphasis on Communication, Critical Thinking and

Creativity. There is also, perhaps, a passing reference to Character, with students being required to vouch for the provenance and originality of their work.

It should also be noted that the IB assessment omits yet another “C”, and it is significant that, despite deliberately finding words that begin with “C” to describe what is valued in 21st-century education, there is no mention of “Competition” in the 6 Cs - yet another point of difference between the IB and the NSW HSC methods of ranking students. Indeed, given that the IB assessments are marked according to rubrics that are known in advance, there is no incentive for students to strive for relative superiority; thus raising the possibility that students’ Citizenship and Collaboration skills may also benefit from this style of assessment regime.

It is therefore the case that the quietly omitted C of Competition may be the most contentious and problematic member (or non-member) of the “Cs” of education. It is arguable whether competition has any place in education, but until we cease to rank students for competitive selection, competition is necessarily present, whether overtly or not. While the IB’s score-to-rank conversion obviates the need for IB students to be aware of the competition, the existence of this conversion plainly demonstrates the need for IB students to be competitively ranked; and indeed from a social perspective the conversion can only exist while the IB maintains its status as a niche product, available only to a select few. Since the lack of choice in assessment regime for government school students naturally raises questions about equality of opportunity, if the IB gained significant market share, it would be more likely to require defence against questions regarding the potential for socioeconomically advantaged students to benefit from their ability to choose the assessment method that best suits them. Perhaps equally important, the mapping of IB scores to absolute tertiary entrance ranks will require some reconsideration, especially if it becomes more generally understood that the IB effectively creates an unlimited number of ATARs above 99. It is clear that this system of ranking would become unworkable if all students had the same opportunity.

4.4.5. Lessons From IB Maths Assessment

> ➢ **Research Question 3**
>
> What do mathematics teachers perceive to be the characteristics of assessment methods that enable and encourage the use of mobile technologies?

The IB offers a glimpse into what assessment could be like, but its characteristics also bring to light the difficulties that could arise when catering to a larger and more diverse student population. The graphing calculators change the nature and difficulty of the mathematics that is worth assessing; the written report is more suited to motivated students who would be more likely to do their own work; and the non-competitive nature of the system quickly becomes problematic for the purposes of competitive ranking. All of these issues must be satisfactorily addressed before IB-style assessment can be considered for mainstream student populations.

However, all of these characteristics are relevant to considerations of mobile learning in mathematics, and the IB assessment regime provides insights into the ways in which mobile learning may impact upon mainstream mathematics teaching and assessment. As Philip noted, permitting graphing calculators in the IB mathematics examination meant that calculator use "has to be taught"; and in so doing, the nature of the mathematics being assessed must necessarily change. Since it is not at all clear that such a curricular change is unequivocally beneficial, consideration must be given to the extent to which technology might act as a crutch for students with gaps in their understanding (e.g. Stacey, 2014), and whether it in fact serves to widen the achievement gap between students who are keeping up with the curriculum, and those who are not.

The use of mobile technology in creating an assessable artefact (such as the written report) is one way in which mobile learning can be integrated into assessment without changing the nature of the mathematics that is examinable. Issues regarding the doubtful provenance of assessments completed outside of supervised examinations are inevitable for such assignments, and therefore it is perhaps too much to ask for the results of such assessments to contribute inordinately to competitive ranking. The IB's proposed solution gives weight to such an assessment, without allowing it to dominate the final mark, thereby suggesting one way in which the construction of a quality artefact might be encouraged whilst minimising potential mercenary effects.

> **Research Question 2**
>
> How do traditional mathematics assessments influence teacher perceptions of the effectiveness of teaching with student-centred mobile technologies?

Philip's experience with mobile learning suggests that, while it may be pedagogically beneficial for the more highly-achieving students, the abstract nature of the mobile device's representation is not necessarily suited to all. The benefits of mobile learning can therefore be outweighed by the conceptual leaps required of students who are not ready to progress to this level; and it is ironic that, with the potential to differentiate learning for all students, mobile devices are yet hampered by the limitations of a 2-dimensional interface, and mobile learning does not give teachers licence to re-interpret the syllabus outcomes expected of students at each year level. Indeed, it may be argued that the technology helps to normalise expected achievement levels by providing convenient access to rote learning and repetitive practice - both old-school methods not unlike Philip's use of whiteboards with his lower-ability students, which can improve student assessment outcomes without making use of any affordances that are unique to mobile learning.

4.5. Case Study: Chesham House

Chesham House is a private co-educational Christian school located in a quietly affluent part of metropolitan Sydney. Catering to years K-12, the school recently introduced student technology ownership from Year 5, with students encouraged to purchase an iPad for use through Years 5 - 8. The transition to a laptop computer occurred during Year 8, with no particular device being specified for Year 8, but by Year 9 students were expected to own a Macbook. Although it was not mandatory for students to purchase a particular brand of computer, there was an expectation from the school that the students would obtain the recommended hardware - an expectation with which the great majority of students complied (Patrick, CH1 0:02:42)

Although the school accepts primary as well as secondary students, mathematics teacher Patrick only took classes for Years 7 - 12. At the time of the interview he taught four mathematics classes: the third Year 8 class (of five), the top Year 9 (accelerated), the fifth Year 10 class (of five), and the second class for Year 12 2-Unit mathematics (NESA, n.d.c). In addition, he was the boys' advisor for Year 7, and the specialist mathematics teacher for a Year 8 STEM class. Observations were conducted with his Year 8 and Year 9 mathematics classes.

Patrick's use of technology spanned his entire six-year teaching career. In the process of doing this, he developed an appreciation of the technological affordances that suited his practice:

> Sort of worked out what's worked for me, over the years. I've tried some things and thought, no I don't like that. And I think there's big value in it, but I also think there's still a lot of value in the traditional approach as well. (Patrick, CH1 0:01:51)

While student-centred technology was a constant presence in his classroom, Patrick noted that the technology was often replaceable with more traditional paper-based alternatives, and in many instances the technology was just used to deliver static content in a more convenient form. Patrick also regularly utilised technology-based resources such as Maths Online and Mathletics, which may be comparable, although not functionally equivalent, to hard-copy textbooks and paper worksheets.

> The Mathletics is, normally they're ten-question quizzes. And the positive thing about it is instant feedback. And a variety of grading questions. But also, there's an ability to differentiate it pretty well. (Patrick, CH1 0:05:13)

For Patrick, Mathletics offered the ability to run a more traditional lesson, with direct instruction and student practice, but with the added benefits of formative assessment and differentiation. Apart from the convenience of immediate automatic marking, and the ability to support more timely corrective action, Mathletics allowed Patrick to effectively stream the students within his class, and choose the content that was appropriate for them.

> They can set up groups for your classes to say, even in a streamed class, these are my ten strongest, the ten in the middle and then there's five ones who are a bit weaker. You'd set them [indicating the strongest group] not as much basic stuff and some harder stuff, set them [indicating the middle group] some reasonable middle of the road, and then focus on some of the foundational things for the weaker students. And you can sort of differentiate that way rather than just saying, everyone must do this. I've found it really useful for that. (Patrick, CH1 0:05:13)

Patrick tended to use Mathletics during class time for "a weaker class in the younger year groups" (Patrick, CH1 0:04:35), but had not tried it for his senior students.

> With Year 12, we haven't. I've never set work for them on that. I mean, that's something that we've, as a faculty we've discussed as well, that we've sort of, for some of the older year groups, particularly in the calculus-based courses, we're not really using that resource. Just sort of thinking about how we can do that better. (Patrick, CH1 0:04:35)

4.5.1. Educreations and YouTube

Chesham House runs a program called the Teacher Improvement Model, which encourages teachers to attempt different pedagogical approaches to try to develop their practice. In 2016, as part of this scheme, Patrick chose to create a flipped learning experience whereby he would record videos of his lessons for Year 9 5.3 Products and Factors, and Year 9 5.3 Indices, and then upload them to YouTube for his students to access.

> [I] said, I'm committing to this. I'm committing the time to it, and I'm putting those two whole topics, I'm only delivering resources - I'm only delivering content to them that way. I'm not actually going to stand up and teach. (Patrick, CH1 0:06:48)

Rather than film himself teaching, Patrick used the screencasting app Educreations to create the lessons:

> You can't see me. So, it's almost like a Khan-academy style video. (Patrick, CH1 0:08:38)

Patrick found that, with this teaching strategy, he was able to deploy his attention in the classroom more effectively. By outsourcing the direct instruction component of his teaching to a pre-recorded video on YouTube, Patrick had more attention to spare for managing the students who were inclined to misbehave.

> Behaviour management was an issue with them, and I'm not having to manage their behaviour. Because I can stand at the back of the room, and say, "You've got two options. You're watching, or you have your textbook open." (Patrick, CH1 0:13:07)

Patrick's release from whole-class teaching also meant that he had more time available to help students who were struggling, so that he could tailor his instruction for the particular needs of individuals.

> I got the sense that, for the most part, the time was better spent. I got to spend better time with the students who had the right attitude, and wanted to do the right thing. In class, helping them. I felt, certainly for those two or three weeks, my time was better spent, in class, than it would have been otherwise. (Patrick, CH1 0:13:07)

4.5.1.1. YouTube and Quantitative Formative Assessment

One interesting side-effect of creating lessons in this way was that Patrick was able to get a rough idea of how many students had accessed the lesson content. YouTube maintains a view count as well as statistics regarding the average amount of time spent watching the video, and so while it was not possible to tell which students had watched the video, and which students had not, Patrick was able to use quantitative data to evaluate the effectiveness of this lesson delivery method.

> I can tell roughly from the view count, because they're the only ones I'm setting it for. It's not - well, it's a public resource, but it's not as if ten thousand people are watching it. It's linked to twenty-five students, so if there's ten views, then I know that fifteen kids haven't done their homework. [But] I can't tell whether individuals, someone has watched it three times because they're trying to understand more. (Patrick, CH1 0:09:40)

Despite this, however, Patrick felt that he knew the students in his class well enough to be able to tell which students had accessed the lesson content, and which had not:

> I did it at a point where I already knew them a bit … I knew the ones who were the ones that would do exactly as I'd asked. I knew the ones who would go above and beyond, and I knew the ones who would do the absolute minimum to try to stay out of trouble (Patrick, CH1 0:10:19)

and through his knowledge and understanding of individual students, Patrick was able to make reasonable deductions regarding their level of engagement.

> I don't have exact data on who was doing what, but just intuitively I knew who was doing what. And by the questions that people were asking as well. Some would say, "I've watched this one and I really still am struggling, can you help?" - Sure. Others were saying, "Oh, don't worry, I've done it all," - but I'm saying, well I know you're one of the weaker students, and one of the stronger students has found this challenging. There's some problems there. (Patrick, CH1 0:10:19)

4.5.1.2. Attention Span and YouTube Norms

As well as a view count, YouTube also offers statistics regarding the amount of time people spend watching a video. Guo (2013) describes an analysis of engagement with online educational video content which found that, for the purposes of keeping an audience engaged,

> the optimal video length is six minutes or shorter - students watched most of the way through these short videos. In fact, the average engagement time of any video maxes out at 6 minutes, regardless of its length. And engagement times decrease as videos lengthen: For instance, on average students spent around 3 minutes on

videos that are longer than 12 minutes, which means that they engaged with less than a quarter of the content.

When creating his video content, Patrick researched the length of video that he should aim for; and his recognition that shorter videos were more effective for audience engagement (see Figure 4.10) led to a strategy of developing filmed lessons that were as short as possible.

I remember doing some reading around this as well. The length of time that they watch it for, it did peak. It drops off at some point, I forget what the number was … sort of like three or four minutes. A lot of people will watch a learning video for that long, and then go, I'm over it. (Patrick, CH1 0:15:23)

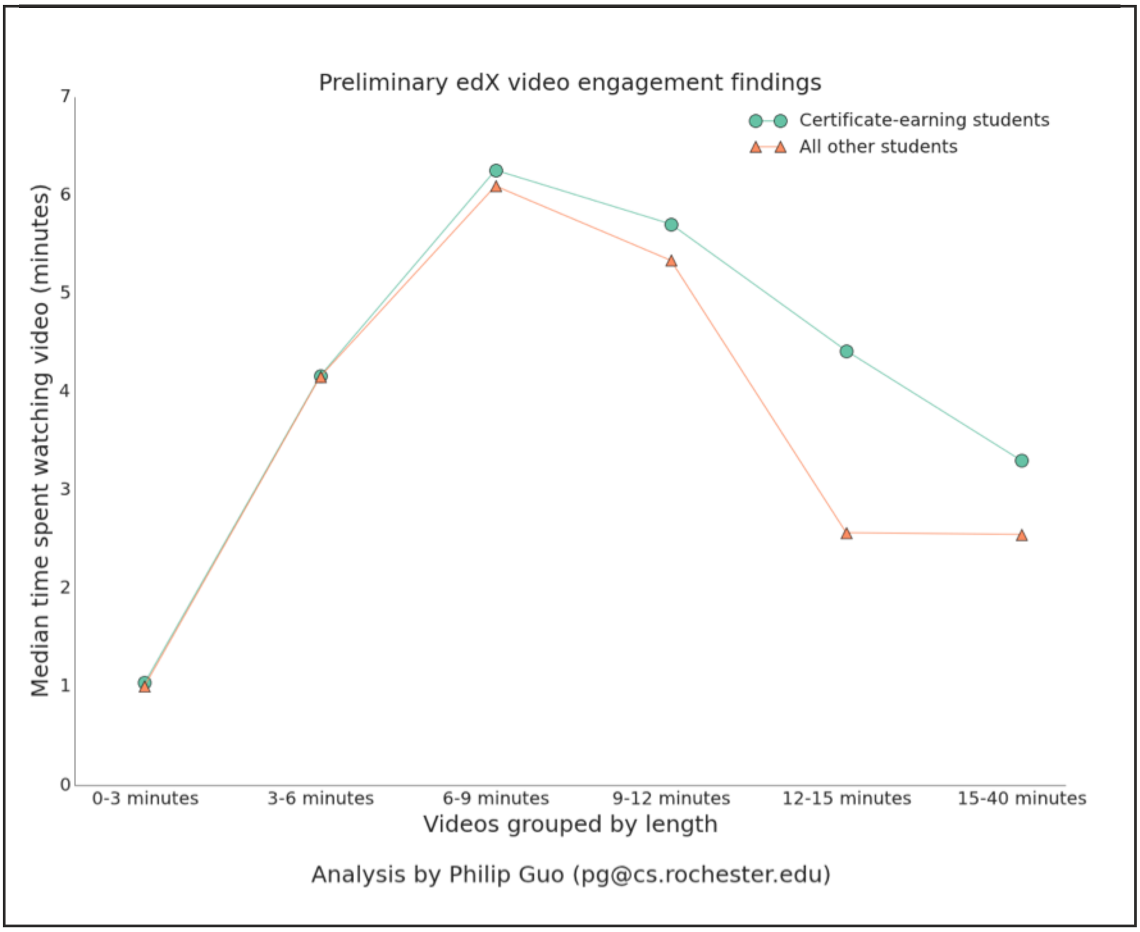


Figure 4.10. How long will students spend watching an educational video? (Guo, 2013)

Patrick aimed for “six to eight minutes at most, or even shorter” (Patrick, CH1 0:14:09), and when a lesson required more time for explanation, he tried to break it up into multiple separate videos. This way of working caused changes to the ways in which he thought about lesson content, so that multiple videos might cover content that would be conceptually similar.

> Trying to really say, OK, it’s a ten minute video. I can’t cut it down … what can I do? All right, let’s make it, Factorising a Monic Trinomial - Really Easy Version. Factorising a Monic Trinomial, Slightly Harder Version. And the third one, Factorising a Monic Trinomial, Really Hard Version. And, rather than going, oh let’s do these things in one hit - sort of chunking it a little bit. (Patrick, CH1 0:15:23)

While Patrick was not able to find out which students had watched his video, or how long they were engaged with it, he was able to find out the average amount of time people spent watching any one video.

> Not, this is the fifty watches, this is how long they have - You might be able to find that data, but, I got the average watch length. That sort of gave me a bit of an indication as well, that some were not finishing it. (Patrick, CH1 0:16:28)

The inability of YouTube to pinpoint which students were engaging with the video, and which were not, tended to limit its effectiveness for individualised formative assessment. However, the analytics did appear to offer meaningful feedback to Patrick for the purposes of modifying his pedagogical approach; in particular, his interpretation of the average watch length led to a realisation that “if there was anything valuable, [to] get that in very early” (Patrick, CH1 0:16:28).

4.5.2. Pre-Recorded Teaching and Summative Assessment

While the use of pre-recorded lessons significantly changed the teaching and learning experience in Patrick's classroom, its effect on summative assessment results was obviously going to be more subtle. However, Patrick believed that there were particular benefits in relation to the lesson's availability when students were revising previously learnt concepts.

> I think the value comes when, with something like that, when they need to do some revision, they can do it themselves, and sort of re-learn that theory that they need to. It's not the personalised "I don't get this question" help, but it is sort of a re-explanation of what we did in class. (Patrick, CH1 0:14:09)

Patrick's experience of teaching via YouTube led him to conclude that this pedagogical choice benefited students who were keen to learn. His perception that

> [for the] three or four students in there who really didn't want to be on task at times - for them, much of a muchness perhaps. But, for the students who wanted to be on task, I think they had a much greater opportunity to be on task (Patrick, CH1 0:14:09)

indicated that he believed that, on the whole, the teaching strategy would result in a net gain. Indeed, it was clear that Patrick had a positive experience overall with this teaching method; and most students, when surveyed regarding this pedagogical approach,

> said that they liked it more, or the same amount as what they did in class - there was only one or two that said they don't like it. So most actually found it a really positive, really positive experience. (Patrick, CH1 0:08:56)

The effectiveness of this teaching method for improving summative assessment results was, however, less clear cut. Patrick had taught the same content in other years, prior to creating the YouTube lessons; and when asked if the students tested differently after learning the material through YouTube, his response was non-committal:

> Um, quite a hard assessment that they did after that. Just, for the year, it was quite a challenging task. (Patrick, CH1 0:11:33)

With the quantitative nature of summative assessment implying a quantifiable difference in learning, Patrick questioned the reasonableness of comparing different teaching methods:

> If you've got some students who've done something differently, you probably want to compare it to a very similar group of kids who've done it a more traditional way. You'd want to have a school where there's 300 students in a year group … to make a fair comparison. (Patrick, CH1 0:12:28)

Patrick's reluctance to comment on its impact on test results was interesting, not so much for its actual effect as for what it may suggest regarding Patrick's attitude towards this teaching method. With a response that implied that assessment results perhaps did not necessarily compare well with results from previous years, it was apparent that Patrick was unwilling to attribute lower scores to the change in pedagogy. Indeed, it appeared that Patrick viewed the use of pre-recorded lessons as an innovation which preserved all of the benefits of traditional teaching whilst offering a number of additional advantages - such as the ability for students to watch the lesson multiple times, and the ability for Patrick to essentially duplicate his own presence in the room and thus focus his own energies on classroom management.

4.5.3. Assessment Mechanisms

For mathematics assessment, Chesham House included a number of different mechanisms that offered different ways for students to demonstrate their learning. These assessments contributed significantly to students' final marks, since, as Patrick noted,

> Done well, I think they have to be at least sort of ten, fifteen percent. I think for this Year 7 one next term, it's a significant percentage. 20%. Because it's weighted similarly to an assessment, to a standard written assessment. (Patrick, CH1 0:20:36).

Innovation in assessment was ongoing, with Year 7 students trialling an assessment task (see Appendix A-17) which had in the past been conducted as a non-assessable learning activity.

> With Year 7 last year, [they] were still all written assessments, but we ran an incursion for them, sort of a problem solving activity run by an external company. This year, we've decided to assess them based on that. (Patrick, CH1 0:17:41)

For this assessment task, students would be put into groups to work on problem solving activities, while teachers would be "working with them in the groups and seeing how they're interacting and seeing what they can produce" (Patrick, CH1 0:18:04). The assessment therefore combined an objectively assessable component which comprised the production of correct answers, and the teachers' subjective judgements of other skills, such as teamwork (Patrick, CH1 0:18:25).

Other alternative assessments included the submission of work from an excursion to an environmental research centre, a Year 9 Financial Mathematics assignment

> to go find a job they wanted, find the salary, calculate the tax, any deductions you might want to make, and those sort of things (Patrick, CH1 0:19:04)

and a Year 11 General Mathematics statistics assignment based on an in-class vertical jump test activity. However, Patrick's own experience of alternative assessments was relatively limited - "it's just coincidentally I've not taught a lot of year groups that have done this" (Patrick, CH1 0:21:04), and perhaps coloured slightly by an assessment task that did not work out so well:

> We tried as well, a presentation lesson, so they had to present a short lesson. I had a very weak Year 8 class when we did that, and they just didn't enjoy it. (Patrick, CH1 0:21:04)

4.5.4. Effects of Examinations

> ➢ **Research Question 2**
>
> How do traditional mathematics assessments influence teacher perceptions of the effectiveness of teaching with student-centred mobile technologies?

Despite the introduction of innovative assessment mechanisms in mathematics, Chesham House continued to conduct most of its assessments through written examinations. Patrick found that his use of mobile technology in teaching tended to change in the period prior to an examination, but his perception was that the change was due more to student expectations than his own inclination.

> I would say [mobile technology is used] more in the learning stage. And that's probably not actually from my preference. It's probably more just from the students. I think, when a test is approaching, students sort of get this mindset that what I can tell them is of such greater value than what I can provide for them. (Patrick, CH1 0:23:23)

Patrick offered the experience of his Year 9 class as an example of how students would react to the idea that they should be able to rely on mobile learning to prepare for an examination.

> That block of lessons that I did last year with Year 9, it ran right up towards their exam. And towards the end, some of them were going, "So when are we going to stop this, and when are you going to start showing us things again?" So, how am I not doing that now? It's just different. (Patrick, CH1 0:23:23)

Interestingly, despite the Year 9 students' anxieties regarding the teaching method, Patrick maintained their course of mobile learning through to the examination, rationalising that he believed in its effectiveness, and also that he needed to see the process through to completion. His choice indicated that, while the pedagogy was experimental, the effectiveness of this method compared favourably with his own appreciation of the efficacy of direct instruction. In addition, it appeared that Patrick sensed that switching to direct instruction at that point would undermine students' perceptions, not only of the value of mobile learning, but also of his faith in their ability to learn independently of direct instruction.

> On one level, it's probably not the time to turn around and say, well I know they've got a hard test coming up. They've gone from Year 8, being the second class out of five, to Year 9 5.3 where they're really the bottom class, out of two. (Patrick, CH1 0:23:23)

The experience of this Year 9 class from 2016 contrasted with the data from observations of Patrick's Year 8 class (3rd of 5 streaming tiers) in 2017. With observations at Chesham House being scheduled for just a couple of days prior to an examination period, this class was observed actively preparing for the test by learning unit conversions, techniques for calculator use, and mnemonics for remembering formulae. When students were directed to practice on their own, they produced both devices and textbooks; and of 25 students, five used hardcopy textbooks, and the remainder used either softcopy textbooks, Mathletics, or Maths Online. Discussions revolved around strategies for answering multiple choice questions ("Statistically it's more likely to be the longest answer") and test-taking techniques such as doing questions out of order.

4.5.5. The Effects of Teaching with Technology

> ➢ **Research Question 1**
>
> What do secondary mathematics teachers value in student learning with mobile technologies?

Yet another observation, this time of Patrick's accelerated class in Year 9, served to demonstrate the variety inherent in Patrick's pedagogical choices. Although this class also had an examination coming up in the following week, Patrick had decided that the students were coping and the revision lesson could wait; and so he had planned a technology lesson for the benefit of the observation. Thus the students spent the period "playing" with the Desmos "Marbleslides: Lines" activity. In this game, students would graph lines on a Cartesian plane to act as ramps for marbles to slide down. The aim was to have the marbles roll over ("collect") all of the yellow stars.

The students proceeded to engage with the activity, making choices that appeared to be highly experimental and not particularly calculated. However, the thinking involved in the game became evident when a student discovered that she could not complete the puzzle shown in Figure 4.11. Working with a partner, she had determined that the slope of the graph would decrease when she decreased the *x*-coefficient, but she had not yet worked out how to give the *x*-coefficient a value less than 1.

The subsequent discussion between this student and her friend ("How do you make it flatter?") demonstrated the value of the technology for supporting higher-order thinking and for providing authentic opportunities for collaboration in problem solving. Although the software was evidently designed with teachers in mind, with student work automatically returned to the teacher and the inclusion of classroom discussion tools such as the "Pause" and "Anonymize" buttons (see Figure 4.2), the technology as it was used in this instance clearly had a student focus. In particular, the technology allowed the

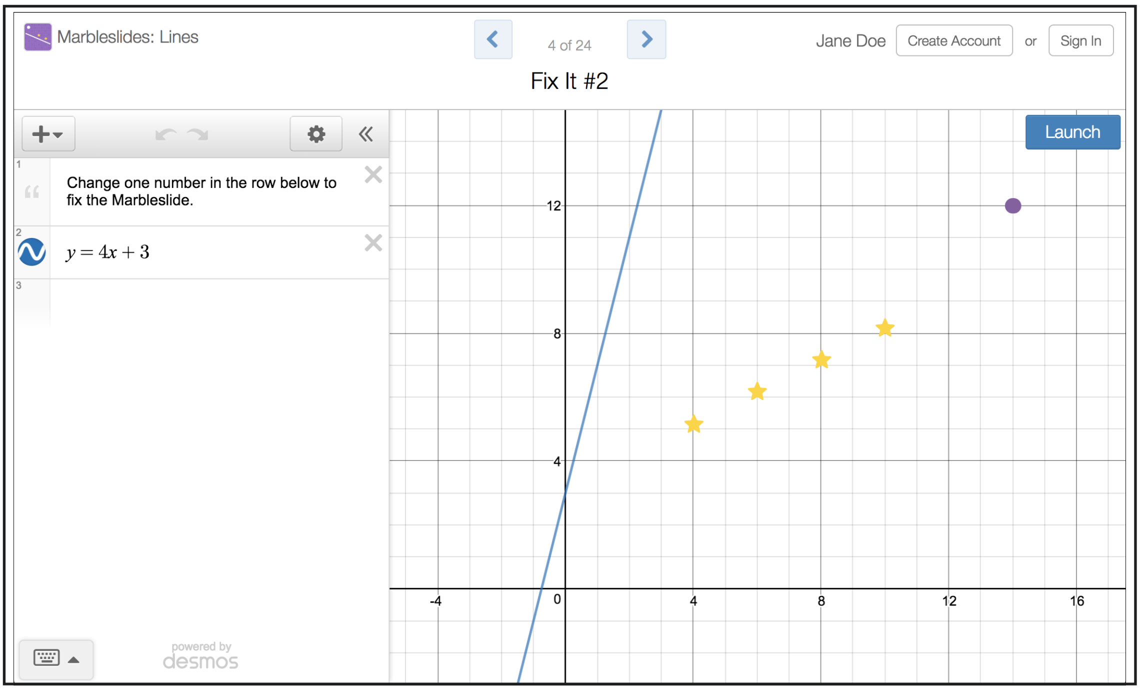


Figure 4.11. Screenshot from Desmos "Marbleslides: Lines" activity.

students to progress at a rate that suited them; and so it was that there were two boys, referred to as the "brains trust" who, by the end of the period, were doing the final free play activity and subsequently approached Patrick with "Sir, look at this work of art."

As well as allowing students to work at their own pace, each Marbleslides puzzle was also amenable to being solved in a number of different ways. Although the class did not discuss the solutions during the observed lesson, it was evident that the game-like nature of each activity meant that it supported multiple methods of solution - a feature that meant that the students could attempt the work, not only at their own pace, but also in ways that made sense to them. With such variety in solution methods, the technology offered significant potential for classes to be run where students would learn from peers who approached the problem differently, and thus all of the students could be supported to develop greater understanding of the material.

4.5.6. Assessment and Streaming

Like many discussions of secondary school mathematics teaching, Patrick's explanations of pedagogical approaches and classroom activities tended to be given with reference to the students' levels of mathematical achievement. The description of an activity was invariably prefaced with the class that it was designed for, including that class's position in the achievement hierarchy - descriptions such as "Year 8, third class out of five". Indeed, Patrick's experience with teaching a highly varied class had given him a personal appreciation of streaming, and an understanding of how streaming helped him to deliver the right level of content to his students.

> Streaming definitely I think has a big impact on how you do things. I'm teaching once a fortnight, a Year 8 STEM class. I've got students in there who are in the weakest mathematics group with very significant behavioural issues, and I've got

> students who are at the very top of the mathematics group as well. And trying to pitch a lesson at them, is extremely difficult. (Patrick, CH1 0:26:46)

Patrick noted that, as Chesham House was a relatively small school, the issue of variability in student achievement was particularly problematic. Since the students still exhibited the full range of abilities, there was inevitably greater variation within a single class, even after the students had been streamed.

> If you're doing 200 students, you can separate things out a little bit more, with the scale of things. But when it's a smaller cohort, you're really tied a little bit. (Patrick, CH1 0:24:16)

With potentially wide variation in students' mathematical understanding, Patrick identified the creation of assessments with appropriate levels of difficulty as being a significant challenge for his school, and for secondary school mathematics in general. He described the issues with a recent examination for Year 10 5.3:

> Year 10 group that did an assessment task last week - not mine, but the Year 10 5.3 group … So many reasonable students have not done as well as you would have hoped, because it's just hard [to] get the assessment at the right level and the right length. Preparing kids for Extension 1 who, in just over 12 months, might be considering Extension 2, and then other kids will be going into General. It's chalk and cheese. (Patrick, CH1 0:24:16)

Since decisions regarding streaming were based on a student's rank following an assessment, the two issues were inevitably closely linked; and so it was interesting to note that Chesham House recently introduced some mixed-ability grouping for Year 7:

> [In] Year 7, we have a top group, and we have a fifth group, and then classes 2, 3, and 4 are mixed. So they are literally the 26th through 100th students in the group, and they're jumbled in any way (Patrick, CH1 0:25:41)

and also for Year 9 5.2:

> Year 9, because we've got this accelerated class, the top two classes are actually streamed traditionally. Top 22 students and the next 25, or whatever it is. And then the third and fourth classes, the two 5.2 classes, they're mixed. So again, that's students 50 through 100, and they're jumbled. (Patrick, CH1 0:26:21)

The choice to run mixed-ability classes for the middle tier of students was significant because, as a new initiative, it was evidently a considered choice. While Patrick noted that there were often impracticalities associated with streaming Year 7 students who had only recently begun attending the school, the deliberate de-streaming indicates that the previous policy of streaming these students did not offer significant pedagogical advantages. Indeed, it may be argued that, since variability would be expected within a de-streamed class, the knowledge that the class is mixed may subtly influence the teacher's approach, so that the teacher may be more mentally prepared for the need for differentiated teaching (Boaler, Wiliam & Brown, 1998).

Thus it was interesting to note that Patrick's technology use allowed him to differentiate the learning for his top Year 9 class - a circumstance that, as discussed in response to the research question regarding valued learning, was evidently an important consideration for Patrick's practice. With Mills, Ablard and Gustin (1994, pp. 496 - 497) claiming that variability in ability and knowledge among students in the top 3% was as great as that found within the general student population, Patrick's class would likely have exhibited as great a range in achievement as that seen in a middle mixed-ability class. The observed lesson therefore offered indications of how technology might support teachers to run a lesson that is differentiated, not by task, but rather by outcome - a method that would allow all students to access the same content, thus avoiding many of the issues inherent in classifying students according to their perceived achievement levels. However, it was also significant that the class was considered to be high ability, as such a circumstance could raise questions regarding the suitability of this teaching method for students who may be less interested, or less motivated.

4.6. Case Study: Elm Park High School

Elm Park is an academically selective government high school in NSW. The selection process for entry into the Year 7 cohort is conducted exclusively through a series of examinations administered by the NSW Department of Education's High Performing Students Unit when students are in Year 6 (NSW Department of Education, 2017c), with examinations comprising three multiple-choice test papers for Reading, Mathematics, and General Ability, as well as a free-form Writing test. Students receive an aggregate scaled score which is used to rank them for entry into their selective schools of choice (NSW Department of Education, 2017a). While the school has no direct influence on the student intake for Year 7, the school conducts its own selection process for entry in Years 8 to 11 (NSW Department of Education, 2017b).

With 14458 applicants for 4226 Year 7 places in 2018 (Smith, 2017), entry into academically selective high schools is fiercely competitive, and it is common practice for students to receive extracurricular tutoring or coaching in the lead-up to the selective schools examination. To illustrate the amount of tutoring that is considered to be normal, a student interviewed by the Sydney Morning Herald said:

> I didn't have much tutoring. I was doing Saturday classes for three and a half hours. (Mahdi Mourad, as quoted by Smith, 2017)

At the time of the first interview, Daniel had been Head Teacher of Mathematics at Elm Park for two years. Prior to this appointment, he taught at Redbridge High School, another academically selective government school, for just over seven years. His time at Redbridge saw the advent of the Digital Education Revolution (DER), a government initiative that provided funding to support schools in introducing digital technologies:

> I think the DER really took off seven years ago, and if I remember the political history of it, Mr Rudd gave us the funds, or at least the NSW government managed it, and then roughly in 2009-2010, a lot of installations were happening. That was a game changer. (Daniel, EPHS1 0:02:22)

Daniel's experience at Redbridge was coloured by his observations of teachers' attitudes towards having student-centred mobile technology in class. In particular, he noted increased behavioural issues:

> At school, almost all forms of mobile devices were seen to be bad. Because students weren't explicitly taught how to use it responsibly, for their own benefit, as opposed to just Snapchatting with them … and quite often, there would be inappropriate circumstances where there were being prank calls from other, you know, students in the corridor - in the classroom down the corridor. (Daniel, EPHS1 0:02:22)

With a lack of consistent disciplinary policy surrounding the use of mobile technology, teachers chose to curtail its use in order to maintain control of the classroom.

> So back then it was seen to be - you know - get rid of them, or some comprehensive schools would even have strategies such as, you know, walk into the classroom, put your mobile device in the tray please, and we would shut the cupboard. (Daniel, EPHS1 0:02:22)

Within the mathematics faculty at Redbridge, Daniel was a relatively early adopter of technology for classroom use. Initially, however, the technology use was limited to the ways in which it might serve as a

> convenience tool for teachers … only because we were transitioning from this phase of, mobile devices bad, therefore put it away. We used it so that we could

> do demos, on the screen, with online tools, and maybe the odd YouTube video, as opposed to getting the kids to use them. (Daniel, EPHS1 0:04:26)

Daniel admitted that, for classroom teaching purposes, he still personally favoured teacher-centric mobile technology use. He positioned himself on a continuum - between colleagues who were

> pre-retirement age, or even in their forties and fifties, who might not be pre-retirement, but they're - because they've not operated with this sort of tech for the last twenty years of their teaching career, it doesn't come natural to them, that they can suddenly jump on these tools to use it (Daniel, EPHS1 0:05:20)

and a more recent graduate in his faculty who used Kahoot!:

> Every now and then, to, you know, the last period of the day, sort of thing, just to keep the kids engaged, on task. Awake, and not, oh, come on, counting the minutes to 3 o'clock … Whereas, even for myself, it's a much bigger readjustment for me to then start to create those sort of resources on Kahoot!. (Daniel, EPHS1 0:05:20)

Daniel believed that his older colleagues felt uncertain about the technology, particularly with respect to its increasingly tenuous links with the world they grew up in. The lack of a hard-copy manual was offered as one example of how software was changing in ways that did not sit comfortably with older teachers' ideas of usability; and with increasing reliance on online delivery of information, Daniel perceived that the more experienced teachers were feeling increasingly marginalised, as their accustomed modes of operation were being gradually devalued.

A related factor that Daniel identified as contributing to the older teachers' reluctance to incorporate mobile technologies in their practice, was a school culture that defined teachers' obligations as being limited to their paid working hours. His reaction to the discovery that this mentality was entrenched within his faculty demonstrated his apparent unfamiliarity with this way of thinking, revealing a considerable cultural divide between his attitudes and those of his colleagues.

> They're fiercely protective of their private hours. Basically private hours are considered off-limits … A lot of the staff here have the mentality that, anything after three o'clock, forget it. Anything that impinges on my own family time, forget it … I respect the people who, OK, want to protect their own family time. I do believe there needs to be work-life balance. So, there is the resistance because of the extra, sort of, screws being tightened, from the government level, and the push back from the militant unionism that this school has, I think, experienced. (Daniel, EPHS1 0:07:21)

While Daniel recognised the validity of the other teachers' perspectives, it was clearly not a mode that he was prepared to adopt for his own practice.

> To be quite honest, I'm not in this position, as head teacher, by doing all of my work nine to three. And I don't think any new head teachers will be able to get their jobs at a promotional level, doing their jobs nine to three. It's always going above and beyond. And part of it would be, to explore the tech pretty much in your own time. (Daniel, EPHS1 0:07:21)

4.6.1. Streaming of Mathematics Classes

With a student selection process that included a mathematics examination, Elm Park could assume a high level of mathematical competence in all of its students, and so it only offered the highest possible mathematics course for students in Years 7 - 10. This contrasts with most comprehensive schools, which offer multiple levels of mathematics in Stage 5 (Years 9 - 10) - from a potentially modified Life Skills curriculum, through various combinations of the syllabus content for Stages 5.1, 5.2 and 5.3 (Board of Studies, 2012). At Elm Park, there was no choice; all students must participate in Stage 5.3 mathematics through to the end of Year 10.

Despite this, however, mathematics classes at Elm Park were rigorously streamed, and until 2017, all 120 students in a year cohort would be placed in classes according to their ranking following their examinations. While the classes were given names corresponding to the teacher's surname, rather than their position in the grading system, "behind the scenes, there was still a hierarchy, 1, 2, 3, 4" (Daniel, EPHS1 0:18:10). Daniel's perception of this practice was that the ranking of students was incompatible with current thinking in educational psychology, and that teachers who preferred such streaming practices were, despite their years of experience, "off the rails".

> Some of them insisted that the exams, the assessments, be paper-based only, pen-based only, and the worst part was, be able to sort every kid into their rank. And when that happens, at a school like this, yeah, you'll get a number 1, with a ten-mark gap, but what has it done for the other 119? What has it done for the other 119 in terms of a whole-school approach to growth mindset? Especially the ones at the tail end? A school's results are always dictated by the tail end. Trashed - literally trashed the 2-unit class. 2-unit class average was running at 45%. (Daniel, EPHS1 0:40:28)

At the time of the interview, a new streaming system had just been instituted whereby students would be chosen for two of the classes by virtue of their results in Algebra and Geometry.

> We look at their Yearly exam results, or their cumulative results, and then try to see where they were relatively weak at. So rather than rank them 1 to 120, which was the previous practice, we then looked at, OK, well, these are the sections that were grouped. Algebra, the kids that were really needy, shove them in one class, feed them more Algebra.
>
> … [Students who] didn't perform as well in the Geometry, usually were not too bad with their Algebra. So they were the ones who preferred to churn through the Algebra, but refused to draw a picture, for example. Relatively weak with their Geometry, put them in one class.
>
> … Then you've got another 60 that are left over. The top ones will go into the "A" class. (Daniel, EPHS1 0:16:14)

With this system, Daniel recognised that "the Algebra class is not performing in terms of test averages, as good as the Geometry class" (Daniel, EPHS1 0:18:10). He attributed this to the greater weighting accorded to Algebra in mathematics tests, but noted that he was hopeful that his streaming method would improve overall results for the students in the Algebra class. In particular, he believed that having an Algebra class would allow the class as a whole to be drilled more intensively on Algebra problems.

> We're hoping in a couple of years' time it turns around some perceptions, of the weaker students, that they can still do maths, but quite often it's the lack of practice. (Daniel, EPHS1 0:18:49)

4.6.2. Rote Learning and Drill

Since his arrival at Elm Park two years previously, Daniel has been made aware that his stance on drill and practice was particularly contentious, and he has had to defend his pedagogical ideas to the school community.

> Even last year I was writing a massive spiel on - there were a number of parents at this school who did not believe in rote learning. They believed it was bad, and questioned, in fact, why my arrival suddenly meant a lot more homework. (Daniel, EPHS1 0:18:49)

Daniel believed that lack of drill was the reason that students underperformed (Daniel, EPHS1 1:25:20). To illustrate the amount of drill that he considered to be necessary, he remarked that the school's chosen "Cambridge" textbooks for Years 7 - 10 did not contain enough practice questions:

> Getting homework from the textbook, they'll not do good enough. The textbook is, in fact, quite terrible for the lack of drill … You can do every single question in Cambridge Year 7 - 10, you still don't have enough to be able to do well at Year 11 and 12 level. (Daniel, EPHS1 0:18:49)

To counteract this deficiency, Daniel supplemented the Cambridge text with photocopies of exercises from two other textbooks: the first edition of Mathscape, and ICE-EM. He explained that, while ICE-EM was not a "NSW-flavoured" textbook, it contained material that was relevant for the purposes of teaching in NSW.

> The primary authors being, well, Sydney Grammar … Peter Brown, Garth Gaudry, etc. Those who've been in it for literally forty years. And these are their observations over the forty years of teaching it, which I have to say, you know, is

> very finely distilled. And they've written it so that they know that this stuff will get the results, if the kids do it. So you can write as good a textbook, but if they don't do it, then forget it. But they're trying to meet it from the, we've done our responsibility part. (Daniel, EPHS1 0:20:19)

Daniel's position regarding drill and rote learning extended to an appreciation of the role that coaching colleges played in boosting his students' achievement:

> The coaching colleges, rightly or wrongly, gives them more time for drill. Even the principal is in agreement that, you want to do well in a sport, you get the best coach. You'd probably get two best coaches. Well, you're not going there - all right - you're not doing anything about your homework either - you're opposed to drill … How are we going to get your results up, when you're not willing to meet us halfway? (Daniel, EPHS1 1:25:49)

and he expressed a firm belief that if students achieved highly, the results would be largely attributable to the students' attendance at coaching colleges.

> There were teachers here, who saw the great results as their own, but it's really the coaching college's … So I've been trying to change that mentality of the teachers - no, you go and teach them a terrific lesson, a blastingly good lesson, each and every lesson. Please. And when the end of year HSC results come through, you know, at most half of it is yours. At most. It's more often than not less than a half. But you need to get it to a half, as much as possible. (Daniel, EPHS1 1:27:35)

Having taught at a coaching college himself for three years, Daniel was able to bear witness to their practices. In addition, he was able to use the coaching colleges effectively to his school's advantage (see Teaching Schedule in Appendix A-18).

> We tell our kids … if you're going to go somewhere, please go somewhere that tries to reflect what you're doing at school. Now this is not always possible, but what we have done on our public website is we have published student editions of the entire teaching programme. If the coaching college sees that, and they decide to take on board our sequence, great. (Daniel, EPHS1 1:26:32)

4.6.3. Student-Centred Mobile Technology

As head teacher, Daniel's teaching load was relatively light. He taught one of the two Year 12 Extension 2 classes, the Year 11 2-unit class, and two periods per fortnight each of Year 10 and Year 8. The Year 10 class was the "Geometry" class, which comprised students who needed more help with Geometry. The Year 8 class was the "A" class, comprising the thirty students in Year 8 who had achieved most highly in their Year 7 examinations.

Daniel chose this level of involvement with the two junior classes "just to keep myself in the loop" (Daniel, EPHS1 0:11:30) and, with each junior class timetabled for seven periods of mathematics per fortnight, he considered himself to be a "very minor shareholder" (Daniel, EPHS1 0:11:49). However, he noted that his involvement with junior classes gave him more opportunities to use student-centred mobile technology.

> The juniors, we can do a bit more. There's a bit of leeway to wriggle. There's no End of Year 10 sort of benchmark that they've got to meet … Juniors there's a bit more flexibility, especially with the "A" class, [which is] usually the enrichment class. We try and do a bit more enrichment with them. And so I would spend the time with them, using mobile tech with them ... I have said to the majority shareholder teacher [of the Year 8 "A" class], you look after the rest of the content, because they're supposedly going to be able to get through it anyway. So I've got the liberty with that class to do it. (Daniel, EPHS1 0:12:23)

He contrasted this with the senior classes, with their heightened sense of impending external assessment.

> The way that the senior courses are structured … very written based, and not as much room and leeway to cut some content out, in order to fit in some extra bits of the usage of mobile tech into the teaching and learning. I mean, the Geogebra gets whipped out, but, again, it's me focused. … The bottom line is HSC exam, so therefore you've got to get through the course. (Daniel, EPHS1 0:12:23)

Thus Daniel's patterns of mobile technology use in class reflected his view that technology use was either teacher-centric, or a non-core extension activity. During the class observation in late August (less than two months prior to the HSC examination), his Year 12 Extension 2 students watched attentively as Daniel worked questions on a whiteboard, on which was projected particularly curly examples of past HSC problems (Figure 4.12). Daniel's teaching during this demonstration indicated his expectation that all of the students were performing at a very high level - the explanations were fast and

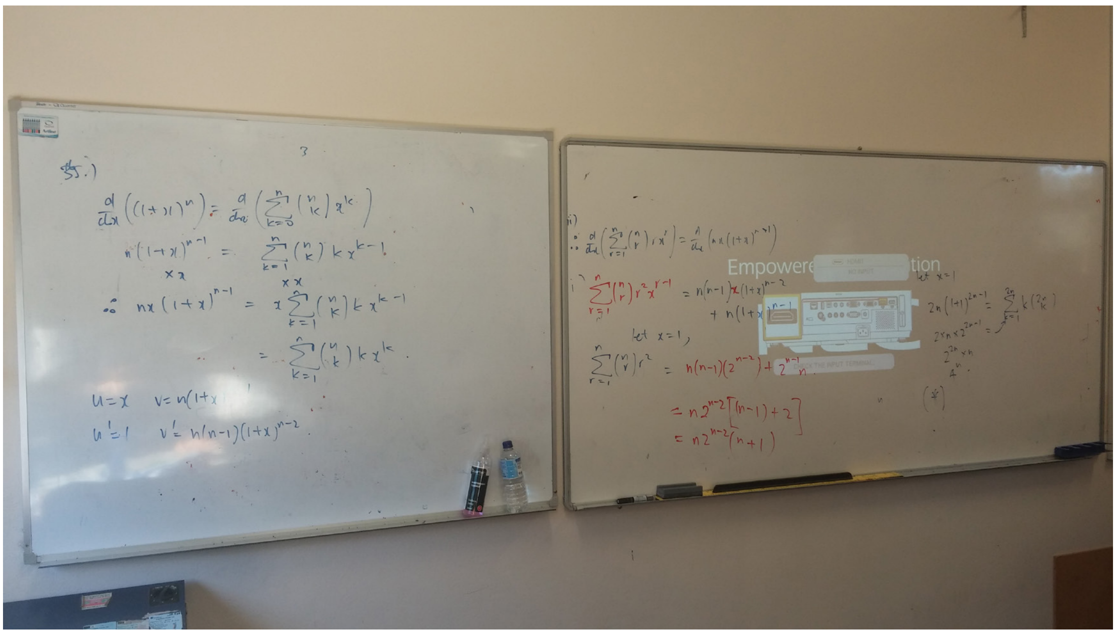


Figure 4.12. Whiteboard following Year 12 Extension 2 class.

efficient, with a particular emphasis on taking care with working rather than verifying that students were able to keep up.

Although the observations offered no examples of mobile devices being used for anything more than content delivery, Daniel believed that technology-enabled enrichment activities particularly benefited the higher-achieving students because their experience of learning mathematics had revolved largely around written work.

> It's to try and change some of their perceptions, because a lot of the "A" classes would be off at tutoring some other time. And so the tutor would be trying to do pen and paper. (Daniel, EPHS1 0:12:23)

This contrasted with his views regarding what was best for students who were not achieving as well. For those students, he rarely used mobile technology.

> The Algebra and Geometry classes [are] the ones that, maybe, as an end of term activity, do it, but otherwise they'll need the structure. They'll need the very rigid structure to get them on track. … They tend to have less concentration, to start off with. You whip out the mobile devices, quite often - [my colleague], she did it last year. With the top classes, it wasn't really much of an issue, but the bottom class, they started putting stupid names into their aliases. So, it's behavioural. (Daniel, EPHS1 0:14:28)

4.6.4. Technology for Real-World Application

Daniel's appreciation of mobile technology as an enrichment resource was relatively narrowly focused, so that his usage of the technology was carefully considered in terms of measurable learning outcomes. To illustrate the extent of the student-centred mobile technology use, Daniel described the activities for his Year 8 class, for which he allowed himself the most freedom to experiment pedagogically:

> It's a little bit more fun during those two periods. We've gone into Excel, working with Excel, looking at videos, etc. (Daniel, EPHS1 0:15:38)

The relatively limited nature of the in-class mobile learning reflected a prevailing sense within the staffroom that the teaching should be "focused on the bottom line" (Daniel, EPHS1 0:38:51). Elm Park's mathematics faculty consisted largely of what Daniel referred to as "career maths teachers" (Daniel, EPHS1 0:39:51) - individuals who had been mathematics teachers for their entire working career. Daniel's appreciation for their commitment was tempered by an awareness that "retrainees from industry" (Daniel, EPHS1 0:35:39) brought insights that were potentially valuable for student learning.

> There's that general lack of experienced retrainees from elsewhere who can link up stuff and then bring the online bits in … Bring the online bits and pieces to try and bridge the students' learning. We've been harping on about STEM and it's not going to happen, in reality, because of the lack of retrainees. The career maths teachers are not necessarily going to see the applications, nor are they going to understand the applications in engineering. (Daniel, EPHS1 0:36:36)

Daniel's own path took him from an unfinished electrical engineering degree to mathematics education, a trajectory that gave him an appreciation of the potential for real-world applications to enrich the teaching of mathematics.

> I can talk to some of my staff with AC curves - the sine and cos waves, for example - and they'd have no idea that it was exactly the stuff coming out of a power point. For them, it's just, "Oh, really? I never knew that!" … But they see it as, far too technical, it's not in the syllabus. (Daniel, EPHS1 0:38:16)

Thus, with a lack of teachers who had first-hand experience of real-world applications of mathematics, Elm Park's mathematics faculty only used technology that was designed specifically either for mathematics or for education.

4.6.5. Technology for Communication

> ➢ **Research Question 2**
>
> How do traditional mathematics assessments influence teacher perceptions of the effectiveness of teaching with student-centred mobile technologies?

It was apparent that an overarching sense of obligation towards preparing students adequately for assessment contributed significantly towards Daniel's choice to use student-centred technology only when it demonstrated clear, direct links to assessable outcomes. This stance led to the use of technology primarily for the purposes of communication. The school, as a whole, has an externally managed "Sentral" server that supports Moodle for student communications, but Daniel considered this platform to be both unstable and unsuitable for communications in his faculty.

> Every time they apply an update, it breaks something … Other faculties use Moodle. But for us, I saw it as one-way traffic. For us, the way that we were using it, before 2015, was that it was just a tool to dump PDF files on. (Daniel, EPHS1 0:56:41)

The need for two-way communications led to some classes experimenting with Google Classroom, but this also posed logistical problems for teachers.

> [The students] don't rename the image files. So you get image001, and you go, what the heck is that? And the poor teacher's having to sift through the thousands

> of pictures to see what's going on. And you can't give feedback immediately, by writing on [it]. (Daniel, EPHS1 1:00:47)

Daniel discarded Moodle in favour of Edmodo and OneNote, two applications that served complementary purposes for communication with his students.

4.6.5.1. Edmodo

Daniel's initial forays into the use of mobile technology for student communication at Elm Park were directed towards providing a backup method for accessing class hand-outs. The purpose was to remove a potential excuse for not performing set tasks, and to allow teachers to expect timely work completion.

> We've gone sort of back to basics with paper, but at the same time, with mobile tech, we now try and upload a copy of what we hand out as well … They're going to lose things. Executive function / organisation is one area that we're trying to work on, and to close the loophole for them to say, "I've lost my hand-outs, sir." No, it's on Edmodo - go and fetch it. (Daniel, EPHS1 0:23:16)

While the use of Edmodo may have rendered the paper copy essentially redundant, Daniel was adamant that the printed version was an essential part of the transaction. He cited a former colleague from Redbridge, who said that, at least with boys, it was insufficient to put everything online:

> That particular staff member saw the good things that could be happening online, but he said, "With boys, don't just go online. They're not going to download it themselves." … If you just chuck it online, boys do not go and look at it, unless they're the really toppish lot. Really self-motivated. (Daniel, EPHS1 0:24:15)

Despite the ability of Moodle to support broadcast communications such as these, Daniel introduced Edmodo for mathematics because it allowed him to format mathematics equations using LaTeX, a typesetting system that was designed for printing mathematical symbols. The ability to type equations has meant that Edmodo could be used both to ask elaborate mathematical questions in an online forum, and to have them answered in detail. While the use of Edmodo for these purposes was still in its infancy, Daniel demonstrated the school's Edmodo setup and its ability to support mathematical collaboration:

> So we've created year groups, except for Extension 2 which is an extra year group … At the moment it's a communications platform. Students can actually ask questions. Now it does look like it's a monologue in here [but] it's something that we're trying to change the culture of … This, perfect example. (Daniel, EPHS1 0:55:31)

At this point, Daniel indicated a student's question, followed by a detailed response from a teacher which was formatted in LaTeX.

> You can dump PDF files [on Moodle], but it really lacks the two-way communication. The student being able to ask other students, what can I do here. Or in fact if the teacher decides to jump into the situation, the teacher can jump in, after hours, etc. (Daniel, EPHS1 0:57:56)

4.6.5.2. OneNote

Another initiative which harnessed technology for student communications was a trial of OneNote for the purposes of collecting homework. Daniel introduced this for his Year 11 2-unit class, "which is considered to be the bottom level at a selective school" (Daniel, EPHS1 0:26:06), and cited it as a failed experiment.

> I told them it's on trial. It didn't work out well. I'll share my failings as well - because sometimes, you can learn a lot from failings. (Daniel, EPHS1 0:59:33)

His intention with OneNote was to maintain momentum in the students' mathematics learning, by counteracting the potentially long periods of time that would elapse between mathematics classes.

> We lacked the number of periods. We were having seven a fortnight, whereas my previous school had nine a fortnight, but shorter period lengths. Therefore maths was front and centre every [day] of their life, pretty much. These days, we got two less periods a fortnight. Maths isn't always front and centre, and sometimes, it's four days before you see them again, because of a disruption. So I proposed to them, look, to check homework, let's try this. (Daniel, EPHS1 0:59:48)

The idea with OneNote was that students would take a photo of their work and upload it to their own "pages" for Daniel to mark, which he was able to do by writing directly on his screen. However, the initiative was stymied by technical issues where "they've said they've uploaded it and it shows up with a broken image" (Daniel, EPHS1 1:00:47) and so Daniel decided that the use of OneNote for two-way communication was not worth pursuing further:

> For them, unfortunately the mobile device actually let them down, because it was giving them extra work in terms of just making it work. (Daniel, EPHS1 1:00:47)

However, Daniel found that OneNote offered functionality that usefully complemented Edmodo, and so he planned to maintain it for the purposes of broadcasting information and allowing students to track their own progress.

> What isn't a flop is, they still enjoy the fact that the content library is still there. So, topic 1, classwork and homework. Topic 2, classwork and homework. So they can just copy this page over into their notebook. And I've just created these little tick boxes that they can even tick off whatever they've done themselves … And for all intents and purposes of viewing things on the app, OneNote mobile app is nowhere near as tedious as trying to stick pictures in. (Daniel, EPHS1 1:02:48)

4.6.6. Mobile Device Usage Patterns

> ➢ **Research Question 1**
>
> What do secondary mathematics teachers value in student learning with mobile technologies?

Elm Park's academic focus was reflected in the formal acceleration of parts of the curriculum for the entire cohort. This acceleration was "all done in little sheets and booklets etc., which we can easily whack onto Edmodo as a tiny little PDF" (Daniel, EPHS1 0:52:50), and so students would often work either from a paper booklet or by referencing the same content on their mobile device.

It was therefore the case that the mobile devices were normally used as "a hard copy replacement … one device as opposed to five textbooks" (Daniel, EPHS1 0:53:32), and while Daniel did have students using more sophisticated features of the devices, in general, usage patterns tended not to be interactive.

> The interactivity was - is still - very much an individual teacher thing … What [the Deputy Principal] has been driving as well, for the high quality program initiative, is to try and document all of it here [in the Scope and Sequence] and try and

> provide more optional enrichment options or more little bits and pieces of ICT. (Daniel, EPHS1 0:53:32)

Elm Park's mathematics Scope and Sequence document was annotated with symbols to indicate the potential for using software to enhance the class. Teachers who ran classes with technology were encouraged to evaluate the lesson and document aspects that succeeded. In general, however, the software use tended not to be mobile-specific; and indeed, aside from the use of technology for communication, usage patterns favoured software applications that could be run offline, such as Geogebra and Excel.

> Some of it, in a spreadsheet, you're naturally going to go Excel. And even with Google sheets, sometimes it just doesn't work. The kids lost connection, you know, there's no reception in the room, etc. So it falls apart. So it goes back to an actual offline software application. (Daniel, EPHS1 0:54:55)

4.6.7. Mathematics Assessment

Daniel was a veteran of the selective school system, having attended Elm Park himself as a student, and having taught at Redbridge for seven years prior to his current posting. It was therefore unsurprising that he was sympathetic to the prevailing examination-based assessment culture, and appreciated the benefits that such a culture could offer for students who were academically able. However, he also acknowledged the relative lack of assessment of real-world application of mathematics, and suggested that there would be students for whom such an assessment would be better suited.

> I think STEM was trying to do that. Trying to make maths relevant, in other areas. I'm not sure how successful it is, at this stage … but, I think, if the assessment side of things were able to be less exam-based, in theory I think we could get that

> up. There are kids who, yes, will thrive in an exam. Yet, on the other hand, I think across the state you'll get kids who will thrive when you give them a project to do on their own, it's something they can make, where they apply their maths skills. Or, even, not even mathematics, let's just say numeracy skills. Which is one level lower. (Daniel, EPHS1 1:10:54)

With limited exposure to mainstream students, Daniel's understanding of their learning needs appeared to be largely theoretical. Indeed, with a conception of mathematics learning being defined in terms of the curriculum, and how thoroughly it had been covered in preparation for assessment, Daniel's perspective was heavily skewed towards the needs of students who aspired to university degrees rather than practical application.

> When they progress on to the next level, which is university, for the first three years of it, at least, it will be mostly exam based ... So for most academic purposes, I can't see these sort of [practical] projects being 100% useful. Apart from having it for the sake of having it. (Daniel, EPHS1 1:11:49)

Daniel predicted that external high-stakes assessments, such as the HSC, would continue to be technology-free for the foreseeable future:

> I don't see any deviation from current practice - bringing their own laptop, research on the spot, so to speak (Daniel, EPHS1 1:11:49)

and while he believed that assessment should reflect real-life applications, his view of this was that, under examination conditions, the application must be artificially contrived.

> We are trying to do that ourselves, by setting questions that you can make a real-life example out of the syllabus. (Daniel, EPHS1 1:14:26)

Daniel described a previous year's examination question on Blood Alcohol Content as an example of what he meant. Since none of his students were doing General Mathematics, they did not engage with the Mathematics and Driving focus study, and so questions on Blood Alcohol Content offered a real-life scenario for which they could apply their understanding of calculus.

4.6.8. Examinations versus Investigative Tasks

Given the emphasis on achieving highly in the HSC, it was unsurprising that Elm Park mirrored HSC assessment mechanisms and conducted mathematics assessment exclusively through examinations. In accordance with this focus, it was anticipated that an assessable investigative task would be set later in the year for the current Year 10 cohort. The reason for the proposed change in assessment schedule was to prepare the students for changes in the mathematics syllabus, including a proposed investigative task in Year 11:

> Whether it's per year or per the entire duration of the two years, of their HSC progression, we still don't know. NESA hasn't published it yet. But we are heading down that track, of injecting one per year. We're starting off with Year 10, which is the most urgent - the greatest urgency - in the hopes that it will progress into the lower years. (Daniel, EPHS1 0:29:08)

Daniel expressed some uncertainty with respect to the way in which the school would approach this new assessment method. The lack of clear guidance through historical example had resulted in the school remaining noncommittal regarding how the new task would be assessed.

> We're trying to wait for NESA to tell us what the senior ones are going to look like, and how we should approach it. There are all sorts of ideas out there. It seems that everyone has their own idea. (Daniel, EPHS1 0:30:19)

> ➢ **Research Question 3**
>
> What do mathematics teachers perceive to be the characteristics of assessment methods that enable and encourage the use of mobile technologies?

Daniel believed that the new initiative may potentially provoke misconduct, particularly in academically selective schools where performance in assessment tasks is accorded a high degree of importance.

> Plagiarising off the net, or off a friend, or otherwise. That's the big concern that the selective schools have. Because all of us will operate in a very similar way. That is, the 120 or 150, does exactly the same course, 7-10. (Daniel, EPHS1 0:30:19)

He contrasted this with the local comprehensive school, which would be unlikely to have the problem to the same degree:

> Because we don't offer Stage 5.2, so we can't set a separate one for them … Whereas, I think just nearby, Green Park, would have a Stage 5.1 class, there'd be a Stage 5.1 mixed with bits of 5.2, so they can progress a bit more, that sort of thing. (Daniel, EPHS1 0:30:19)

Since the school had never set project-based assessments, the issue of assessment integrity had never previously been an issue, and Daniel's belief was that examination supervision was sufficient to deter students from attempting to cheat (Daniel, EPHS1 0:31:34). Interestingly, Daniel also theorised that it would be comparatively difficult, if not practically impossible, to detect misconduct in unsupervised mathematics assessments, because the software for detecting plagiarism was not sufficiently sophisticated.

> It's easy to type in the words into plagiarism detection software, have it search online etc. But with maths symbols, how do you do it? If it's handwritten, how do you do it, effectively, without gobbling up an entire working day of your life? (Daniel, EPHS1 0:32:22)

Daniel offered LaTeX typesetting as a possible solution, whereby student work would be converted to LaTeX code and then passed through plagiarism detection software such as Turnitin (Daniel, EPHS1 0:33:10); but he was dubious as to the efficacy of this method without human involvement.

> We haven't reached the stage where we detect handwritten plagiarism. You need a person … And even OCR software, it's got to be able to detect the superscripts, subscripts, simple fractions, etc, and not mis-detect. So there's going to be a high rate of detection and false positives. (Daniel, EPHS1 0:34:11)

4.6.9. Low-Tech Initiatives for Improving Assessment Results

With its intense focus on performance in summative assessments, Elm Park relied almost exclusively on examination results to ascertain the extent of student learning. Students who did not achieve learning outcomes would, in the past, have been issued with a "letter with a massive threatening paragraph" (Daniel, EPHS1 0:40:28) to inform their parents that they had not been working well. Since his arrival, Daniel had attempted to change this culture to recognise students who, despite their efforts, were not achieving at the expected level:

It’s not about a number. It’s about how much you’ve learnt, and how diligent you’ve been. … We do tell their parents if they’re not achieving learning outcomes, but they’ve been diligent, therefore they’re better off ploughing their efforts into English Advanced, for example. (Daniel, EPHS1 0:40:28)

4.6.9.1. Student Self-Reflection

To complement this new approach towards supporting students, Daniel recently introduced a self-reflection sheet (Figure 4.13), which was given to students at the same time as the examination solutions. He noted that the self-reflection sheet had been well received by the teachers, particularly when they had students who needed more help.

Some of the better kids will actually write on it, and in fact for the struggling kids, some of the teachers have really jumped on board with this, and gotten struggling

2017 Mathematics Extension 2 Assessment Task 2 STUDENT SELF REFLECTION

1. In hindsight, did I do the best I can? Why or why not?

....

....

....

2. Which topics did I need more help with, and what parts specifically?

- Q1, 6, 7(a)-(c), 11(a) - Complex Numbers

  ....

  ....

- Q4, 5, 9, 11(b) - Conics

  ....

  ....

  ....

  ....

  ....

3. What other parts from the feedback session can I take away to refine my solutions for future reference?

....

Figure 4.13. Detail from Elm Park Student Self Reflection sheet.

> kids to actually write this down, collect it from them, scan it, as a part of the evidence that they've tried to support the students. And then they're really - well OK, all right, extra class for you at lunch time. (Daniel, EPHS1 0:43:50)

Daniel viewed the student self-reflection as a "tool that we can wield to drive up improvement" (Daniel, EPHS1 0:44:35) and, whilst acknowledging that it did not suit all students, he believed that it was a practical measure that the school could take to support student learning.

4.6.9.2. Examination Feedback Sessions

Another recently introduced post-examination practice at Elm Park was the common feedback session, where all of the students who had sat a particular examination would be brought together to review the papers.

> [Redbridge] have been doing it for yonks, and [academically selective high school Archway] has already been doing that. … They put them in one massive room, solutions are given out, and the marker goes through with them. Common areas are, where they could improve. And students take that on board really well. Whereas we, here, and a lot of other schools, they did it in classrooms with their own class teacher, who may not have marked most of the paper … and there's not a consistent message. (Daniel, EPHS1 0:44:35)

Daniel noted that, while there was little in the way of mobile technology in such sessions, he was able to harness efficiencies that were made possible by other, albeit older, technology.

> Really the only tech here is to be able to get it into this hall. Data projector ... So, there's not much mobile tech at this level, because of the fact that it's still paper-

based. But the new tools that we have had, with data projectors etc, faster printers with stapler, has helped us to become more efficient. (Daniel, EPHS1 0:47:13)

4.6.10. Early Exposure to Senior Curriculum and Assessment Mechanisms

The emphasis on performance in the HSC was also carried through to the junior years. All assessment tasks were formally announced, and following each examination, worked solutions were provided to all of the students (Figure 4.14).

In addition, examinations in Year 10 adopted the style of the HSC.

> We try to keep it as senior-like as possible. And again, it is dictated partially with a view to building them up for the senior courses … So we still want them to set their work out on blank lined sheets of paper which reflects the HSC, which is booklet form, with lines. And give them the self-reflection sheet, just like the seniors. (Daniel, EPHS1 0:48:11)

The formal acceleration of parts of the curriculum was also considered in terms of its effect on HSC results. The rationale behind the choice to accelerate certain areas in

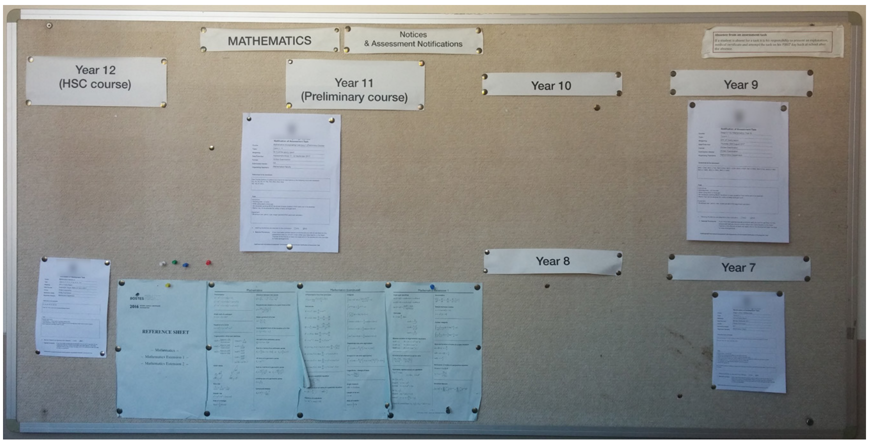


Figure 4.14. Notices for mathematics assessment tasks. (See Appendix A-18 for detail.)

particular, was to give the students more exposure to the concepts that they would likely find more difficult:

> These are usually their weak spots. So to get them to do it, make them assess it once in the, you know, out of normal year, and then assess it again in subsequent years, drills it into them. (Daniel, EPHS1 0:50:32)

4.6.11. Fluency Versus Understanding

Daniel's view that students were best served by acquiring fluency with the practices that contributed towards HSC performance, was reflected in most of the mathematics faculty's initiatives for teaching and learning. However, Daniel also noted that, at least for some students, examination questions may be solved using methods that were not explicitly taught and practised.

> Matching problems with learned procedures [is] probably not as important, because again, sometimes they will come up with alternatives. So there might not be a procedure that we have taught … Taught procedures [are] not the prime aim of the assessment. (Daniel, EPHS1 1:24:43)

This posed a dilemma for Daniel as he strove to increase measurable student achievement. While his main emphasis was on the acquisition of fluency through drill and rote learning, he believed that students whose results were only high due to high levels of application, did not perform as well in mathematics tasks that would benefit from some measure of ingenuity (Figure 4.15).

> Creativity [in] Extension 2, is top notch. Not so much for the other courses. Extension 2, we kept telling them, "You've got to think on your two feet." …

> Actually, in the task that we just set, one of the questions took them down the path of the polynomials at Extension 2 level. Fair enough. But then, the next sub-part, swung around the corner and actually took the Euclidean geometry path. … If they didn't have the creativity to then see it from the geometric perspective, most of them flunked it. (Daniel, EPHS1 1:34:18)

i. Show that the roots of $z^6 - z^3 + 1 = 0$ are amongst the roots of $z^9 + 1 = 0$. **2**

ii. Show that **2**

$$z^6 - z^3 + 1 = \left(z^2 - 2z\cos\frac{\pi}{9} + 1\right)\left(z^2 - 2z\cos\frac{5\pi}{9} + 1\right)\left(z^2 - 2z\cos\frac{7\pi}{9} + 1\right)$$

iii. Show that **1**

$$\cos\frac{\pi}{9}\cos\frac{5\pi}{9} + \cos\frac{5\pi}{9}\cos\frac{7\pi}{9} + \cos\frac{7\pi}{9}\cos\frac{\pi}{9} = -\frac{3}{4}$$

Figure 4.15. Question in Extension 2 examination paper.

While Daniel chose to emphasise the importance of rote learning and drill for success in mathematics, he did not consider this to be in conflict with the apparent requirement for students to exhibit creativity in their thinking. Rather, his position appeared to be that the acquisition of fluency was a fundamental requirement for success; and the creativity was only necessary at the highest levels of mathematics, and only then for the most difficult questions.

> They really needed to have been creative and to be able to see the change, immediately. The change of tack. [Which] a number did, very impressively, but again, most didn't. Which is a reflection of some of them having rote-learned their way through Extension 2. And I think that's where it's very, very difficult. Extension 1, you can rote-learn your way through it. 2-unit you definitely can

> rote-learn your way through it, with almost zero creativity. But I think the HSC is changing tack again in that direction. The last questions, the last two years, have been trying to get at that creativity bit, with the multidisciplinary type problems. (Daniel, EPHS1 1:36:03)

4.6.12. In Pursuit of Academic Achievement

The case of Elm Park offered a unique insight into what matters for students who are able to perform at a high level academically, and the schools that support their learning. While its practices may not be suited to a comprehensive high school, it was apparent that Elm Park fulfilled its promise as a rigorous training ground for high-performing students. Its experience therefore afforded a pertinent, albeit unusual, appreciation of the ways in which assessment - and, specifically, a focus on exceptional performance in high stakes assessment tasks - would influence the uptake of mobile pedagogies.

What was perhaps most striking about the Elm Park case study was the way in which assessment performance permeated all aspects of the teaching and learning experience in mathematics. The teaching was highly focused and, like an elite sports coach, Daniel concentrated on the students' areas of weakness and trained the students to overcome these deficiencies through intensive practice. Areas of particular difficulty were introduced early so that the students would be exposed to those concepts for longer periods of time. With an appreciation that rote learning and drill would help all students to achieve highly in the HSC, Daniel structured his lessons so that he could be sure that all of the students had as many opportunities as possible for drill, and he provided extra material for this purpose to ensure that the content would be thoroughly learnt.

It was therefore sobering to note Daniel's concerns regarding the lower-achieving students at Elm Park, and the way in which the culture of comparison affected their learning. That such an issue existed was particularly notable since students at Elm Park were selected for entry based in part on their results in a mathematics examination, and their primary school's assessment of their mathematical ability, as well as other measures that were considered to be indicative of aptitude for learning. In most comprehensive high schools, any Elm Park student would likely be placed in the top mathematics stream, and be recognised for their academic results. That at least half of these students were deemed to "need the very rigid structure to get them on track" (Daniel, EPHS1 0:12:23), and were therefore offered fewer opportunities for enrichment, particularly with mobile technologies, was largely attributable to their relative performance within Elm Park, rather than their ability to benefit from the enrichment activities. The same students, at any other school, would likely have been judged to be exceeding expectations, and would therefore have been considered to have been able to use mobile technologies responsibly, and given access to enrichment activities alongside other high-achieving peers.

A related side-effect of the culture of comparison, and the emphasis on performance, was the question of assessment integrity and the temptation for students to engage in academic misconduct. Daniel's concerns regarding unsupervised assessments indicated that he foresaw issues with assessment integrity if assessments included components that were not strictly pen-and-paper examinations being overseen by invigilators. It was, however, both curious and telling that academically able students should consider cheating at all. If, indeed, this did occur, then it might perhaps be symptomatic of students' perceptions of the importance of appearing at a relative advantage; but it may also be possible that some students would cheat, not to improve their ranking, but rather as a considered response to what they may believe to be unreasonable study expectations - that is, simply to appear competent, without engaging with the amount of work that the school required.

Daniel's misgivings regarding academic misconduct also encompassed questions regarding the assessor's ability to detect plagiarism in an unsupervised assessment task.

His perception that it was difficult to prove plagiarism in mathematics appeared, at least in part, to be coloured by his experience of mathematics as being largely symbols-based. Indeed, it was apparent that his concerns were highly pertinent for mathematics tasks that consisted largely of questions for which provably accurate, calculated answers would be sought; for there are likely to be relatively few ways in which high school students might solve a mathematics problem. While it was unclear how Daniel's proposed solution, involving the parsing of LaTeX-formatted equations, would be able to address the issue of plagiarism detection, it did suggest that Daniel had formed an idea that a mathematics assessment task must involve numeric or symbol-based responses that lent themselves to LaTeX formatting. This was perhaps indicative of a view of mathematics that would be more aligned with the idea of its being "pure" rather than "applied", and a view of mathematical achievement as being a measure of the individual's ability to think conceptually, rather than their ability to relate mathematics to the infinite variety of real-life contexts.

With achievement in high-stakes assessment tasks influencing all aspects of mathematics teaching and learning at Elm Park, it was unsurprising that mobile technology was only really used as an adjunct to traditional teaching practices that have been shown to have a positive effect on assessment results. Indeed, the experience of Elm Park was not dissimilar to the experience at the academically selective Archway High School, at which students were surveyed for their attitudes towards mobile technology and were found to prefer working with their laptops "in every class except for maths" (AHS, personal communication, November 13 2015). With both students and teachers sharing a common academic focus, there was a sense that any activity that was not directly relatable to achievement in assessment situations was wasted effort.

In addition, the choice to largely eschew student-centred networked technology use within the classroom, in favour of offline applications such as Excel, suggested a hesitancy towards using anything that might run into technical issues and squander valuable face-to-face time in class. Indeed, it can be argued that, despite Daniel's enthusiasm for the technology, mobile pedagogies were considered to be peripheral to the main business of mathematics teaching and learning at Elm Park; and even where the capabilities of mobile learning may enhance the experience of learning mathematics for high-achieving students, current practices at Elm Park appeared to indicate that these capabilities were underexploited. As an example, while Daniel promoted the use of Edmodo for communications between students and staff, most of the messages were broadcast from staff; and while there was an expectation that students would contribute to the discussion, the one student question that we saw was answered by a teacher. It was therefore apparent that, if students were using mobile technology for mathematics, or helping each other with their mathematics learning, then this mobile learning was not occurring on the school portal.

It can therefore be argued that, with Elm Park's teachers using mobile technology mainly for communication outside of the classroom, the main purpose of the mobile technology at Elm Park was for teachers to ensure that students knew what was expected of them, and to establish a backup method for students to access their work. It had not, in effect, displaced traditional teaching methods. Rather, mobile technology at Elm Park appeared to be used as a mechanism that could more efficiently manage the time and attention that both teachers and students spent on the teaching and learning of mathematics.

4.7. Case Study: Moorgate Secondary College

Moorgate Secondary College is a comprehensive high school located on the south coast of Victoria. It was the second of the two schools chosen by the ARC Discovery Project for its championing of teaching and learning with mobile technology. Interviews and observations at Moorgate were carried out with three mathematics teachers - Miriam, Margaret and Malcolm; two science teachers, Scott and Simon; and two English teachers, Ellen and Emily. Ellen was also the assistant principal. In addition, there was a forum held with a group of students chosen by the school.

Somewhat unusually for a government school, Moorgate required all students to purchase iPads for school use, and the school offered payment plans to assist with these purchases. With irregularly shaped classrooms and large common areas, students rearranged flexible furnishings to form work spaces, and traditional teacher-centred instruction was interspersed with periods devoted to self-directed learning, during which teachers were available for one-on-one assistance. Since the self-directed learning was not subject matter specific, all teachers fielded student enquiries in areas outside their own Key Learning Areas [KLAs], and indeed the school deliberately rotated teaching assignments for the junior classes so that staff were expected to teach subjects for which they were not formally qualified.

The school curriculum was integrated with, and in many ways driven by, an assessment schedule that was unique to the school. Years 7 - 9 would participate in a program called "Fuse", which was structured around the school term. For the first seven weeks of each term, all middle school students participated in a "Tutorial Blitz" in Science, English, Mathematics, and Humanities, with additional classes in Numeracy (which was not the same as Mathematics), and Literacy (which was not the same as English). Students also engaged in periods of independent learning, during which they were expected to work on iBook "task cards". Each of the four main subject areas presented a task for the students to complete, and each task was differentiated into four different levels. All students had considerable freedom regarding the levels of task to undertake.

Following the Tutorial Blitz, students moved into a two-week assessment period during which they completed Common Assessment Tasks (CATs) in each of the four subject areas. The CATs were not like examinations so much as assessable class activities; as an example, the CAT for Year 7 mathematics in Term 3 was

> a challenge-based thing where they have an investigative task where there's someone who has a restaurant, and they have to see how they can arrange the tables so [they get] the most people in their restaurant. But the whole point being, how you align the tables gives you algebraic rules. One way it's $4n + 2$, go the other way it's $5n + 1$, which is more beneficial.
>
> And it's an open-ended task where there would probably be about 12 questions, but we stepped the lower kids probably to get up to question 5, the high kid probably to go to the end question. And there would be a lot of drawing and stuff, on grid paper and, you know, rulers. (Malcolm, MSC3 0:17:09)

Following the CATs and prior to the term break, the students engaged in a "deep learning" task, which either developed upon one of the themes from the term or focused on a particular skill, such as collaboration or research.

The school-term-based Fuse structure was bookended with two short tests for each domain area, each of up to half an hour's duration. The pre-test, conducted in either the first week of term or, if possible, in the last week of the previous term, gave the teachers concrete information from which they could plan the lesson content.

> So we know our starting point. So the planning goes from there as well, but also our groupings in Year 9, that's what we look at too, how we can group the kids. (Simon, MSC5 0:14:54)

Following the completion of the unit of work, the students were required to sit a similar "post-test" to ascertain their learning, with the results being used more in a formative than a summative sense,

> just to see - you know, if they've grown themselves, but more importantly, that cohort to see if it's moved or if there's something that we've missed in what we thought we were going to cover … like so the ones earlier in the year, we will look at, can we fit something we've missed, in later, and try and get them more up to speed as a whole. (Miriam, MSC1 0:01:17)

Of all of the school's assessments for middle school students, the pre- and post-tests bore the closest resemblance to the traditional examination format. However, these tests were relatively low-stakes, and in some cases students were permitted access to their written notes while taking the test. Additionally, the pre- and post-tests were sometimes administered on students' iPads, with a teacher in attendance to enforce the expectation that the students would not access the Internet for answers.

There was an appreciation within the school that this curricular structure was somewhat bewilderingly different for students who had previously attended another secondary school; and it was expected that students who arrived in later years would need time to develop an understanding of the format. Thus, for a student who would arrive in Year 9 after having attended Years 7 and 8 elsewhere,

> that's a steep learning curve, for those kids. And I always call parents, pretty much in the first couple of days, just to say, take a deep breath, this is probably going

> to take two weeks before they really start to find their feet, with how some of the terms we use, the Task Cards and the Stages and the Weeblys and where they find stuff and even how we run a day to day timetable. Like, if they're going to Fuse, what does that actually mean, if they're going to Maths, if they're going to Science, if they're going to independent time, what does that mean. You've just got to say, give us two weeks, to sort of walk them through it. (Simon, MSC5 0:05:58)

Moorgate Secondary College chose to engage with this structure after consideration of the reasons for introducing mobile learning. The assistant principal described the development of the Fuse concept as being driven by the need to differentiate teaching for different students; and indeed, during concept development, differentiation was the only requirement mandated by the school. Following its successful implementation for Year 7 and 8 students, technology-enabled differentiation spread to all school years, with a continuation of Fuse into Year 9 and a subsequent differentiated task-card-based system for senior students.

4.7.1. Choice of Pedagogy

Despite the unusual curricular structure and reliance on technological affordances, a reasonable proportion of the teaching and learning at Moorgate Secondary College appeared to be strikingly teacher-centric, with teacher-led direct instruction, and all students engaging in the same activity. Observations of Year 9 introductory trigonometry saw teacher-led explanations of "opposite" and "adjacent" sides, the use of the mnemonic "SOHCAHTOA", and textbook exercises to reinforce the learning. Likewise, a Year 8 science class was instructed on the correct labelling and colouring of a printed diagram of the structure of a cell.

The pragmatism evident in this more traditional approach was, however, offset by lengthy independent learning periods, and novel classes in which students would construct and program Lego robots (Figure 4.16), or indeed "program" a friend to perform a task as though they were a robot. At the time of the observation, computer programming had just been introduced for all Year 7 students, and figured significantly in the Numeracy course, with students writing increasingly elaborate instruction sets using the iPad app "Scratch Jr" after having been given a perfunctory introduction and then told to just "have a play".

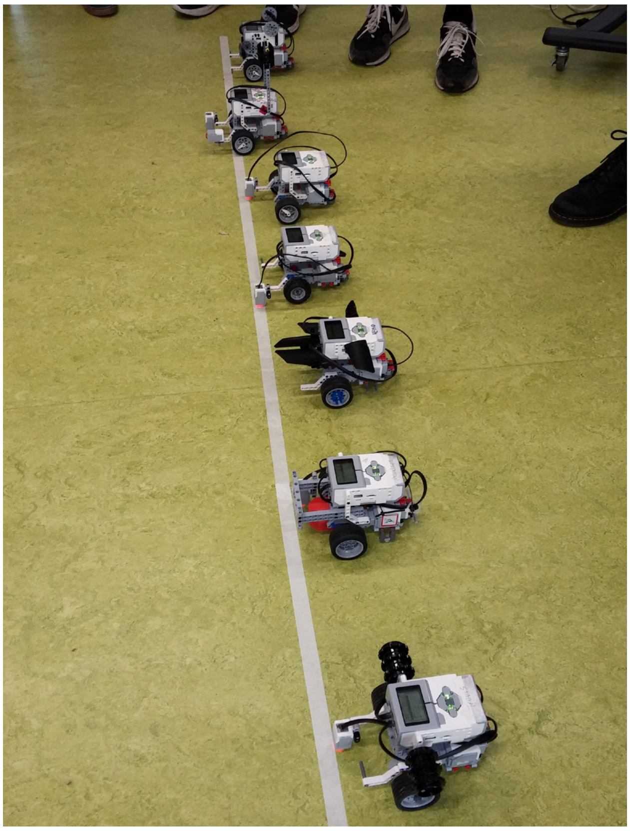


Figure 4.16. Lego robots lining up for a race.

Although the school could justify the innovative classes by tying them to syllabus outcomes, there was yet a sense that the unorthodox nature of some of the instructional methods needed to be balanced with learning that was either more dense, or perhaps more traditionally valued; and it was interesting to note that the school was considering the introduction of Mathletics (Margaret, MSC2 0:09:57), which would tend towards a more instruction-driven and compartmentalised approach towards the teaching and learning of mathematics.

4.7.2. In-class Formative Assessment

> ➢ **Research Question 1**
>
> What do secondary mathematics teachers value in student learning with mobile technologies?

Given the overall emphasis on differentiated learning and student autonomy, it was relatively difficult for teachers at Moorgate Secondary College to employ traditional methods of formative assessment. In particular, the format did not lend itself well to teacher-led pacesetting, and so teachers were not always able to tell if the students had been on task.

> Sometimes it's harder to see how much work they've done, over the course of a lesson, which as a teacher you want to be able to gauge, how much have you done. And then that's easier sometimes in a workbook … and sometimes because they're all at different levels, working at different levels, that can be harder, also. Because, you can't just say, yeah, have you done your ten questions, or have you done this amount. That doesn't - It's a bit harder to judge. (Simon, MSC5 0:17:39)

However, the technology-rich environment at the school, coupled with a collegial understanding that staff should work together to improve their technology use, had led to experimentation with a plethora of educational applications. In particular, the ready availability of the "multiple choice quiz" genre of application had seen considerable interest in its potential for supporting formative assessment. Due to the similarities between these applications, both teachers and students had developed enough of a basic understanding of their operation to be able to use these applications interchangeably.

> We've used a lot of these sort of apps - like Kahoot! … Even if we produce a new app, they've used that Kahoot! app so often that they understand the idea of it. (Malcolm, MSC3 0:04:02)

The application in favour at the time of the interview appeared to be Pear Deck (https://www.peardeck.com), which supported more sophisticated response options that were not limited to multiple choice. With Pear Deck, students could also submit typed responses and free-form diagrams in real time, and the teacher could choose to show the students' original work on the projector screen. The application offered several different viewing options, so that while the teacher could see the names of the students against their submissions, the names would be redacted for the projector display.

In observing a Year 7 mathematics class using Pear Deck for introductory algebra, it was apparent that the content of the lesson was no different to the content that might be covered at a similar stage for a class that used no technology. It was, however, interesting to note that the students would choose to respond to the mathematics questions, even if the response was to say "I don't know"; and indeed, the teacher believed that the use of the technology increased student engagement and their willingness to have a go:

> If you ask a student to write down an equation in detail in their book, they get a little bit bored, but all of a sudden, dragging their finger around where they can change colours and fonts and stuff … Probably a lot of kids - I reckon probably there would have been about six kids there that would have had a go at the equation, that probably wouldn't have done it if it was just in their books. (Malcolm, MSC3 0:00:41)

While the teacher was able to save all of the response data, including all of the statistics regarding "who wrote what at what time" (Malcolm, MSC3 0:02:00), it was apparent that the finer details were considered to be irrelevant, and that instead the data were intended to be used to gauge the progression of the class as a whole.

> Formative assessment … informal way of seeing where they're at, I guess, yeah. I mean, if anything, it would probably help you write the next lesson, yeah, possibly. Figure out what you need to spend more time on. (Malcolm, MSC3 0:02:35)

However, with the teacher view labelling individual responses with the students' names, it was evident that the teacher could see the pace at which each student was progressing - a circumstance that subtly influenced Malcolm's interactions with individual students. This was particularly apparent in an observed exchange between Malcolm and a student who had changed her own, more sophisticated solution method to imitate the method being demonstrated to the class by a fellow student.

4.7.3. Student Self-Assessment

Pear Deck also offered a response option referred to as "Draggable", which displayed an image on the student's screen and asked that they drag a dot to indicate their response (Figure 4.17). The mathematics staff at Moorgate employed this for student self-assessment

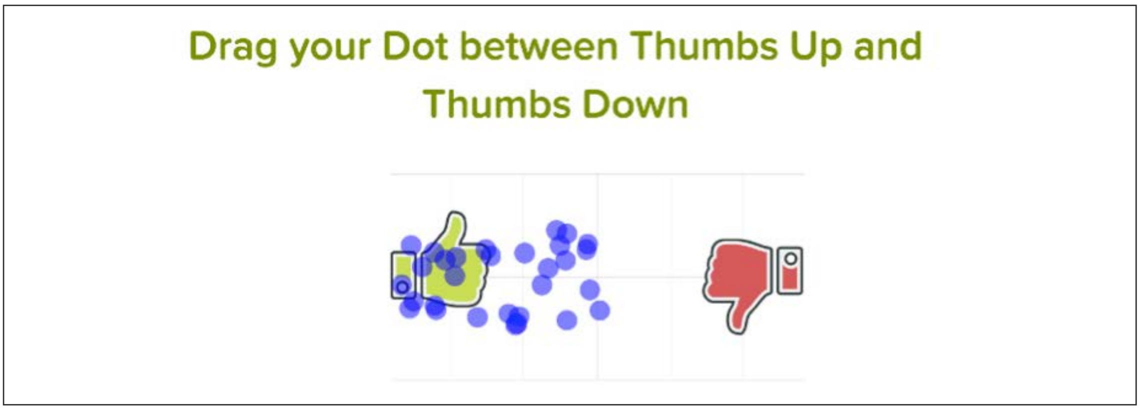


Figure 4.17. Pear Deck "Draggable" student responses.
(http://help.peardeck.com/article/15-draggable-tm-example-question-ela)

in a number of class situations, notably including one such question in the Year 7 class asking students to self-assess their level of confidence with algebra.

The student self-assessments in the algebra class covered the entire spectrum of responses, with a roughly even spread between “confident” (thumbs up) and “not confident” (thumbs down). The teachers clearly accorded significant weight to this indication; it was apparent that this was a metric of particular interest.

> So, over time, it would be really interesting to see if we can get more of those, you know, kind of positive … A lot of people - the kids who are saying that they’re not confident at all, I think a lot of it’s just because it’s all new to them. So it’s getting over - especially with algebra, it’s getting over that hurdle of, I might not know it all, but I know some of it. So I can have a crack, which is just - gets them halfway between not confident, and confident … I’d be happy with that, with algebra, in a Year 7 class. (Malcolm, MSC3 0:02:58)

> ➢ **Research Question 3**
>
> What do mathematics teachers perceive to be the characteristics of assessment methods that enable and encourage the use of mobile technologies?

Student self-assessment figured prominently in the Moorgate culture, with students expected to learn self-awareness and to gain an appreciation for their own level of competence. This was perhaps most evident in the school’s differentiation strategy, which operated across each school year group and allowed students to choose the difficulty level with which they would prefer to engage. With four levels available in the junior years, denoted (in Mathematics) M1, M2, M3 and M4, and three levels for senior students, tasks would be differentiated from basic through to advanced:

> It's lower level [M1] you'll be working with definitions, higher level you'll be putting those definitions into context, and using them on things without too much kind of scaffold (Malcolm, MSC3 0:11:26)

and while students received guidance regarding the level that might be suitable, ultimately the choice of task was up to them.

While there were different tasks for the different levels, all of the students would learn the same content, and so all of the students would participate in the same class, and be exposed to the same teacher presentations. The reasoning behind this was to ensure equity of educational access, irrespective of the students' choices - so that they "won't be disadvantaged if they choose a higher one or a lower one, they'll all touch on the same content" (Malcolm, MSC3 0:21:55); and a reduction in the complexity of the teacher's lesson planning was simply a happy side effect.

The task difficulties were also calibrated so that the distinction would be in aptitude rather than industry.

> A higher level does not mean more work, it just means a little more challenging work, and a lower level does not mean you are going to do two - like it's not, if you're working at a lower level you're not going to do two questions, and a higher level you're going to have to do fifteen questions. (Malcolm, MSC3 0:11:15)

Given the freedom of choice, it was particularly notable that these responsibilities were rarely abused. Students were given to understand that

> you could do the lowest level but you're going to be bored. If you go and do the higher level it'll be more interesting. It'll be harder but more interesting, and I guarantee you'll like it more (Malcolm, MSC3 0:11:45)

and while there were inevitably students who would choose the route of minimal effort, such students were in the minority.

> There's only a few kids who are high that would choose to do the lower stuff out of laziness. And want to just kind of get it done. Like, you just reinforce that there's no reward for getting it done quicker. They're just not learning anything new, which is pointless for them and me, as their teacher. So you just kind of use that, sort of. I think honesty is the best thing for that sort of stuff. (Malcolm, MSC3 0:12:04)

It was evident that the teachers at Moorgate had developed a sense of the levels at which each student should aim to achieve, and so some students would be selected for extension

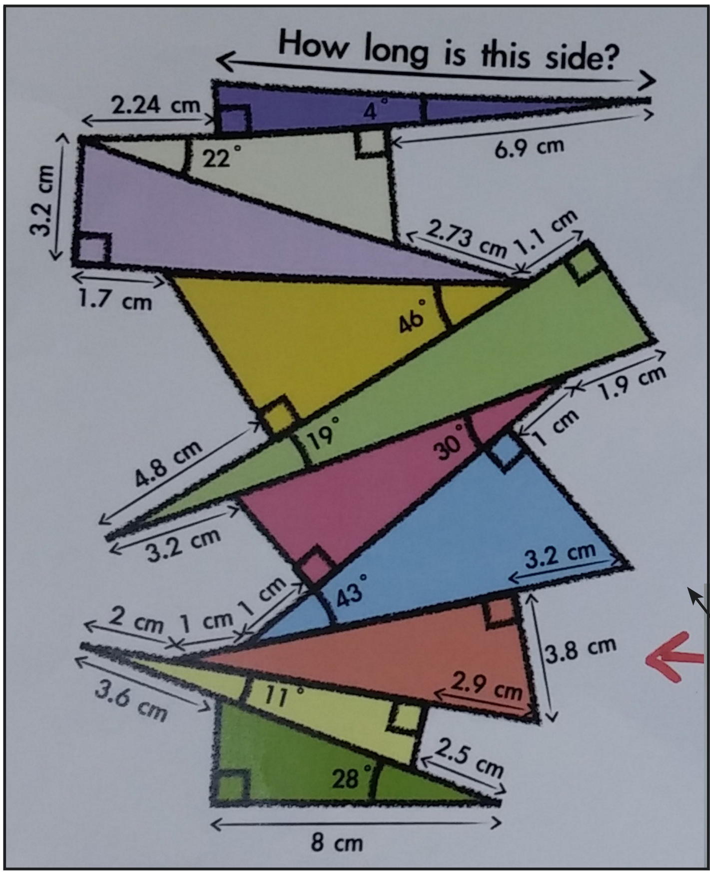
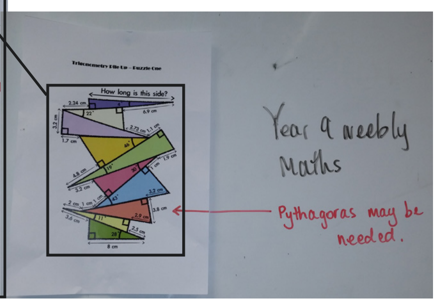


Figure 4.18. Work set for Year 9 top class.



classes during which they would cover more advanced content, including material that may be beyond their year level (Figure 4.18).

> The Extension [Year 9 students] will do a more of a sort of Year 10 level - like we really want to get them to the point where they're doing sort of 3D things with Pythagoras and trigonometry. (Miriam, MSC1 0:08:02)

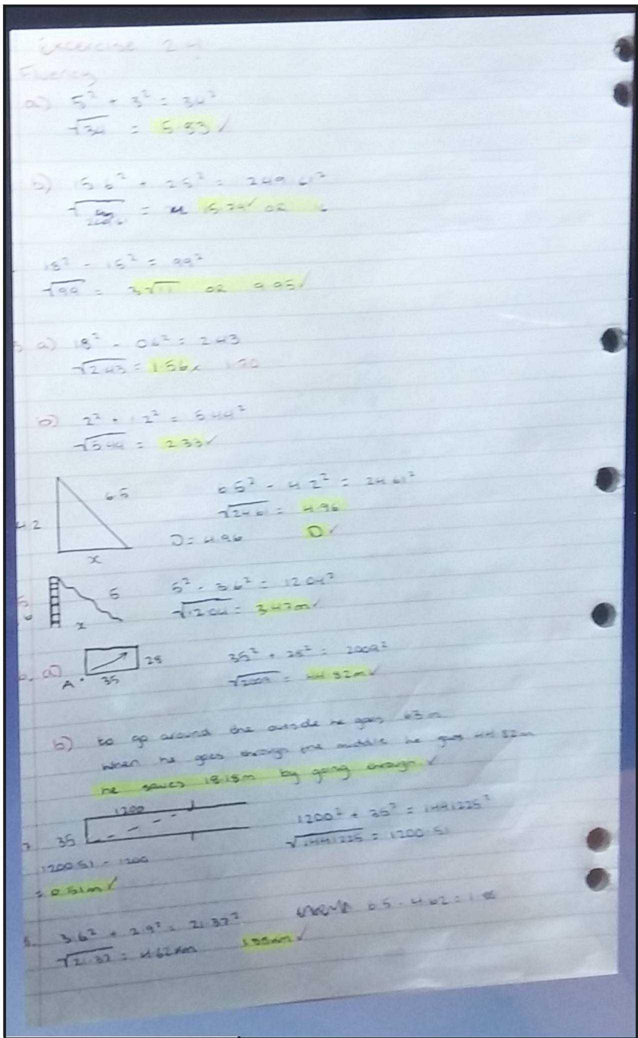
However, for the majority of students, the teachers chose to withhold their judgements, preferring to focus on individual goals and the development of the students' appreciation that they had growth potential irrespective of their current situation.

> We have, particularly in our Numeracy … we have high diversity. … We have this massive tail on us, so it's really trying to get them - and that's sort of the hardest thing is trying to get them to understand that they're still growing, and stop comparing themselves to everyone else. (Miriam, MSC1 0:08:02)

To this end, the school maintained student choice as a fundamental component of the teaching and learning structure, and indeed the resulting arrangement was able to offer a uniquely insightful assessment that reflected the student's own sense of self-improvement. With full transparency in the system, students were able to see all of the task levels on offer; and since students were able to select the level at which they would aim to achieve, progress could be inferred from a student's decision to raise their own goals.

> Definitely we don't want to say, you're M2 … we keep a record of what they've done each term, because we really would like to see that progression. It would be great, M2 last term, try an M3. You could just see them kind of build. Because then the biggest issue you can have is if - if you don't have any movement, you know. If the student just stays at that same level, that's not what we want. (Malcolm, MSC3 0:23:03)

Additionally, students were encouraged to produce something original: the assignments were flexible, as long as their submission demonstrated their development of understanding for that unit of work (Figure 4.19).



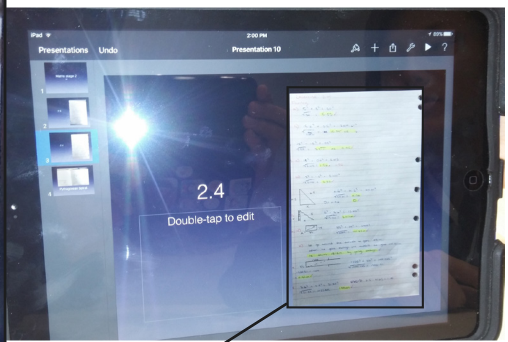
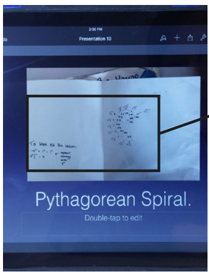
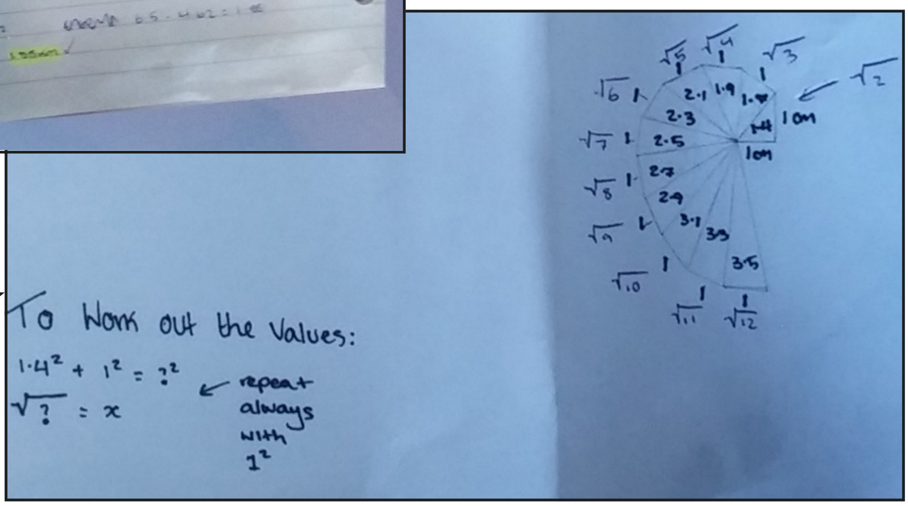


Figure 4.19. Pages 2 and 4 of a student’s task card submission.





> It's negotiable. And they might have to produce a report, or they might produce something, but it might not be on what we necessarily suggest, as long as it's related to the overall topic. Can be flexible, yep. Yeah so long as they still tick off our success criteria, what we've got to assess for, if they can add to it, we certainly encourage that. Make it their own in some sort of way. (Simon, MSC5 0:02:14)

4.7.4. Demonstration of Learning

Although Moorgate Secondary College largely eschews examinations, the curriculum relies to a large extent on ongoing assessment, with students expected to produce assessable work items for each unit's task cards (Figure 4.19; also see Appendix A-19). There were indications that the task cards also, in some way, replaced homework expectations. Even with all of the infrastructure in place for flipped learning, "as a school, the homework culture's not great here" (Malcolm, MSC3 0:34:32); and teachers were adamant that students did not do any more school-related work than was absolutely necessary to keep up (Margaret, MSC2 0:00:36). However, at times students would be asked to engage with a small amount of homework that was directly relatable to the task card activity.

> Like last term, you gotta go home and take 20 different shots there were of angles around your house. And then they had to bring that back into their classroom … They do do a lot of homework at home when they work on their task cards. (Margaret, MSC2 0:10:37)

The task card activity in that case required students to design their own golf course, with students creating angles and shapes using apps like Google Sketchup (Margaret, MSC2 0:14:05). In some cases, the student work would be assessed at different stages for demonstration of some success criteria, to ensure that the student was ready before progressing to the "actual assessment task" (Miriam, MSC1 0:06:38). While teacher assessment clearly mattered for these work items, students were also expected to share their work with their peers and their families; and in such cases the student's submission could be accompanied by an explicit teacher judgement:

> Even when they've put their final work on to Study Turf, that's again we encourage the parents to look at that, feedback, should be in that two-week timely manner. But also if it's an assessable item, it's that Stage 2, the assessment would go up with that as well. Ongoing report. (Simon, MSC5 0:22:34)

or alternatively the quality of the work might be vouched for through its being chosen as an exemplar.

> They had to make [an] interactive poster … Like a cheat sheet, almost, for [students] to use, and then, how, what, is algebra, for Year 7. And then we throw some of those up on to our Weebly … And so I say, "OK the best ones are going to go up." And then they're crazy for which ones are going to go up … They love it. It's good. Just has a bit more, uh, importance on it. Place the emphasis back on them. (Margaret, MSC2 0:14:44)

Peer teaching was an area of particular interest within the school, with students tasked with creating videos to teach each other how to solve algebraic equations (Margaret, MSC2 0:14:05). Indeed, at the time of the interview, these and other modes of communication enabled by mobile technology were being considered as a strategic next step.

> Probably the thing we'd like to shift to a little bit more in the future is the collaborative aspect of online connections. So, not only within our own school, so the kids being able to peer teach, or share their own learning, between each other,

> but also being able to connect to the outside world a little bit more … I think it's probably a good point for us to move forward next. (Ellen, MSC6 0:03:11)

4.7.5. Effects of External Assessment

> ➢ **Research Question 2**
>
> How do traditional mathematics assessments influence teacher perceptions of the effectiveness of teaching with student-centred mobile technologies?

As a pioneer in this teaching methodology, Moorgate Secondary College had few, if any, peers with whom it could compare the effectiveness of its pedagogies and assessment mechanisms. With a large proportion of its assessment conducted through project work, even the school's substitute for a summative examination was unconventional. The short pre- and post-tests that comprised middle school students' entire exposure to examination conditions were considered to be essentially formative, mainly used to ascertain relative progress, to confirm that each student had actually learned something over the course of a unit of work, and to verify that all of the content had been adequately covered.

One of the more obvious concessions to external assessments was the requirement that students maintain paper workbooks as well as conduct work on their iPads, a policy enacted in large part so that the students would not lose their handwriting skills, which would still be necessary for sitting an external examination.

> We have to prepare them to try and do a written exam for three hours. Handwritten, as well, has been difficult. So when I first arrived here, I had Year 9 a couple of years ago. The children were reluctant to actually write, handwrite, and I had to almost, like, retrain them. And they really enjoyed it. They actually really

> enjoyed writing again … They had not been doing that kind of stuff for a while. (Emily, MSC7 0:01:03)

While there were no apparent issues with requiring students to handwrite regularly, a number of teachers across the school expressed disagreement with other traditional examination requirements, with English teacher Emily noting the "disconnect between external exam of English, which is a three-hour written exam … and trying to bring that in to seeing what the students - what their world is" (MSC7 0:00:24). Another canvassed the possibility of allowing students access to the Internet in summative testing situations, observing that such an affordance would be valid if the skills that would actually be valued for life after school were taken into consideration.

> From my background as a scientist, if I didn't know a species name, if I didn't know an organism or what it was doing, I would have to go to scientific papers, do the research, figure it out, and then put it into context. That's the powerful thing of learning. So, getting students to regurgitate stuff en masse is kind of pointless. So, the challenge is to design assessment tasks that can't be copied and pasted from the Internet, but, they can use research and stuff to inform their answers and give justification in their own words, is I think the depth of understanding. (Malcolm, MSC3 0:24:41)

Despite the school's position regarding the reasonableness of such assessment methodologies, it was evident that the students would nevertheless need to demonstrate their competence in external assessments that would disallow such affordances - an issue that has continued to plague the school irrespective of any pedagogical advances.

> We argue with that. We're looking at that as a school at the moment I guess too, because sometimes we can spend so long catering to students' levels, that

> when it comes to an exam that's external, that's where they hit difficulties. (Malcolm, MSC3 0:27:31)

To counteract this issue, the teachers deliberately taught exam-taking technique to the senior students.

> So I write all the assessments, but when it comes to the exam, I make sure that I've bought one externally. So I've said to the students, "Look, I haven't - you know, I've looked at it, the questions seem fair, like we've gone over it, but it's not in my language. I haven't catered to how you guys learn. I'm just like, this is what it's going to be like." (Malcolm, MSC3 0:27:50)

With an appreciation that exam technique was separable from content knowledge, Moorgate's response to the statewide secondary school matriculation assessment regime, the Victorian Certificate of Education [VCE] (VCAA, 2018), was to promote engagement with the coursework material and to give the students opportunities to develop their thinking. As explained by Malcolm,

> if you know the content, you'll be able to answer an exam. So teaching to an exam seems pointless. (MSC3 0:28:13)

The school's faith in the effectiveness of its methodology for the purposes of achieving well in external exams has been justified by its VCE results, which "last year [2015] were actually second in the public system in the Geelong area" (Ellen, MSC6 0:27:36). Notwithstanding this, however, it had also borne criticism from regional representatives for the Department of Education, for its lower than expected NAPLAN results.

> We had a review last year, being our fourth year as a new school, and our reviewers said really complimentary things about the wellbeing of the kids, the kids are really

> happy, very settled, we have a super-orderly environment. The way we structure our learning environments is great, the differentiation is great, the amount of curriculum we have documented is great … But then all they talk about to us was, "Yeah, but you've still got to get your NAPLAN report up." And that was all they were talking about. (Ellen, MSC6 0:26:44)

It was evident that the censure was particularly irritating when considered in light of the importance accorded to literacy and numeracy, relative to other facets of educational practice that are promoted by the regional education department, and yet not as valued.

> So I run a digital learning network in Geelong. So I've got 35 schools involved in that … and the region's talking about the importance of these communities of practice at the moment, and I was like, Great - Now I'll get some support for this, because it's a true community of practice. They're really not interested in it, because unless it's about maths - literacy or numeracy, it's like, not valuing it ... What about all of these other skills, that are equally as important, and we don't talk about, we don't even value the General Capabilities, really, as a system, so I don't know why they bother to put them there. (Ellen, MSC6 0:27:57)

With varying interpretations of what might be considered to be valued learning, Moorgate's philosophy occupied a position that was perhaps more in line with espoused educational aims. As an example, with the aforementioned General Capabilities being defined in the Australian Curriculum to include such skills as "personal and social capability" alongside literacy and numeracy (ACARA, n.d.a), Moorgate actively taught and monitored the acquisition of responsible behaviours and self-management through a number of initiatives, including the gradual relaxation of the rules around iPad usage:

> It's something we talk about regularly, and it's still an issue, but Year 7 and Year 8 they probably do a lot more restricting of iPads, so access to certain sites or games, or, you know, really getting there and putting restrictions on. It's something I do in Year 9, I say, "I don't want to do that. We can. But I'd much prefer you to have access to everything, and be responsible with how you use it, because whether it's next year or the year after … those restrictions won't be there, and if you can't focus on what you need to do, [without being] distracted by something else. I want you to try and learn that now." (Simon, MSC5 0:07:51)

Indeed, in the pursuit of student self-regulation, the school's advocacy for technology use was flexible, with an appreciation that students may need more help to learn to govern their use of the device.

> Certain kids find it really difficult to work with that sort of technology … In the independent learning time, we've got some kids that have got those iBooks that we were talking about, printed out. So they've got it hard copy. They're the kids that, if their iPad is in front of them, they can't just sit. … Some classes, you know, "iPad, on a pile. We're all working pens and paper, we're not even going to touch them today." Because they are students, and they do need that scaffold. But then obviously our goal is that they can be productive while [distracting technologies are present]. (Scott, MSC4 0:14:38)

However, despite the prominence of values such as responsible behaviours and deep learning skills in the Australian Curriculum (Figure 4.20), the absence of tests for these skills in large scale assessment situations appeared to relegate them to a level of relative unimportance.

> There's other things like valuing those interdisciplinary skills. Like creativity, and collaboration. Ethical understanding's one of the General Capabilities, but you know, and then, when we get to VCE though, it's just like, no, it's just content in the subject area, you know, forget all of that other stuff now, you're just going to have to reproduce content knowledge in a format that is going to look like this. Which totally is the opposite. (Ellen, MSC6 1:04:10)

Moorgate Secondary College ultimately reconciled its ideology with external assessment requirements through a concerted effort to teach its students how to demonstrate their knowledge via the accepted constructs for large-scale assessment practices.

> Even if [the students have] got the content knowledge, applied it well … it's understanding the language in those particular questions. So, you know, if it says "Discuss", what does that mean? What's it asking you? Because if you identify something and you don't discuss it in that question, you're not going to get the marks. It's like you're just playing a game. (Ellen, MSC6 1:03:02)

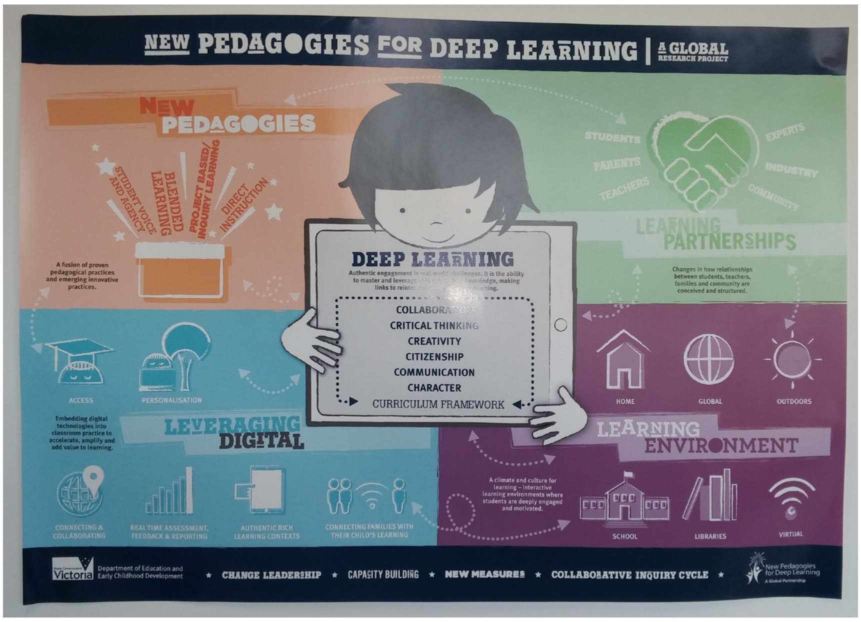


Figure 4.20. Poster on Ellen's office wall describing the 6 Cs for Deep Learning.

Similarly, an appreciation that the students would be exposed to closed-book examination conditions at certain points in their secondary schooling, saw students in all year levels taking the short pre- and post-tests for each topic under normal examination conditions, in some instances without access to their notes.

> We have to teach the kids to get them ready for those exams, or things like NAPLAN too, because otherwise it raises their anxiety hugely, and as a well-being concern you don't want kids to be super-anxious. So you kind of have to make time to just prepare them that way as well. So we do a preparation a lot as a well-being response more than anything else, too. Because kids get so stressed. (Ellen, MSC6 1:05:35)

4.7.6. Implications of Philosophical Differences

With a deeply held belief in the effectiveness of its pedagogical ideology, Moorgate Secondary College maintained a duality of stance that played off student-led learning against external assessment requirements. The result was a highly complex and labour-intensive arrangement which, in some ways, effectively doubled up on assessment - with the school's preference for project-based assessment dominating in the younger years, and an increasing focus on examination-based assessment techniques as students approached the VCE.

It was perhaps unsurprising, then, that the school culture exhibited characteristics that ran counter to simple notions of obedience to external mandate. Instead, as evidenced by the task card assessment system and the gradual devolution of responsibility for the appropriate use of technology, the school actively guided students toward self-awareness and self-referential thinking. In addition, students were continually exposed to the work of their peers, and with full transparency between student, teacher, and parent, students were aware that they always had an audience, and thus there was constantly an implicit question of whether or not they were proud of the work that they were producing.

The Moorgate Secondary College assessment culture attempted to weave theoretical ideals for students' holistic development together with conformity to established assessment norms. However, despite conscious attempts to make allowances for external assessment mechanisms, the school's choice to value student engagement, and its appreciation of the need to cater to students' varying levels of academic development, resulted in conflict with an education system that stipulated developmental milestones for students according to chronological age. Likewise, the school also contended that the requirement to demonstrate competence through the narrow confines of a traditional examination was inconsistent with the educational aims being advocated for by the national curriculum.

It was evident that, through its particular valuing of skills and attitudes that would be relevant for life beyond school, Moorgate Secondary College had created a curricular structure that would guide students towards the development of responsibility for their own learning. With this culture established from the time the students arrived in Year 7, there was an expectation that students would learn to approach their education with resourcefulness and maturity, and acquire the habits of mind that would allow them to solve problems, to explain their thinking, and to criticise their own work. Indeed, the transfer of responsibility for the judgement of workmanship from being merely teacher-centric to include peers, family, and self, obliged honesty of self-appraisal and appeared to provide the groundwork for project-based teaching in the senior years. Students' awareness of what it took to self-assess was promoted throughout their attendance at the school, and the "pointless" exercise of teaching to an exam was replaced with the development of understanding of what the examiner would be seeking, coupled with an appreciation of the necessity to learn exam-taking technique in order to communicate this knowledge more effectively under examination conditions.

Despite some ongoing issues with the distraction of students, it was evident that the mobile technology at Moorgate Secondary College was integral to the provision of a differentiated learning experience that did not prejudge student ability. Indeed, it is difficult to imagine how a school could mass-deliver on both a commitment to differentiated learning, and the development of student self-awareness through experience, without the affordances of mobile learning or some alternative that exhibits similar freedoms. With the acquisition of experience in managing students' abuses of technology, Moorgate Secondary College had seen an evolution of its technology management practices towards a more structured rollout and gradual investiture of students with responsibility for regulating their own use. The resulting maturity of practice allowed the school to maintain the primacy of its fundamental aims of differentiation and holistic student development; and although there was still some disconnect between this pedagogy and external assessment imperatives, there was yet an expectation that matriculating students would have gained an understanding of their own conduct and capabilities, and would be prepared to demonstrate their learning with increased sophistication and integrity.

4.8. Comparisons Between Case Studies

The preceding accounts of seven different schools demonstrate that, despite significant differences in culture and educational philosophy, student learning was yet largely driven by assessment. This idea is certainly not new, having been documented in numerous papers, which in combination demonstrate the potency of assessment in this equation (e.g. Gordon Commission, 2013; Thurston, 1990).

It can be seen that the relationship between pedagogy and assessment figured in all of the case studies in a number of different forms. In particular, the schools employed a wide variety of assessment methods, and so at this point it would be pertinent to consider the characteristics of these assessments and how they aligned with the corresponding teaching methods. In addition, it was evident that all of the schools streamed students to some degree, a pedagogical practice that was invariably informed by results from some kind of assessment.

4.8.1. Characteristics of Assessment Tasks

Given that the assessment tasks obtained for analysis were chosen by the teachers because they were in some way unique or novel, there were few parameters that they could be expected to share, and significant potential for grey areas that may not be easily classified. Thus, the procedure for categorising the assessment documents was somewhat fluid. It began with loose classification of the assessment tasks collected from all of the case studies, a process that was largely informed by prior familiarity with assessment task characteristics. From there, categories were continually refined until different considerations were able to be viewed as separate attributes.

The characteristics that emerged were as follows.

4.8.1.1. Summative or Formative

As noted by Wiliam (2011), "summative" and "formative" are words that describe the function that is served by the assessment, rather than the assessment itself. Thus there were assessments that were clearly used for summative purposes (such as end of year exams) or for formative purposes only (such as questioning in class to ascertain the students' current levels of comprehension). However, there were also many circumstances under which an activity might be classified as both. For example, Elizabeth at Osterley High School required students who had failed a summative assessment to complete the assessment task and resubmit. The action changed the summative result (a fail grade) to formative feedback that may help the student to achieve - a procedure that was not unlike that described by Wormeli (2011). At Elm Park High School, following an examination, Daniel would run debriefing sessions for the entire cohort to ensure that students would learn from the mistakes they had made. Thus for assessments that were designed to be used summatively, the culture of the school often created an expectation that the assessment result was not merely a grade, but rather a means for the teacher to communicate targeted feedback directly to the student - potentially causing every summative assessment activity to assume dual roles.

Indeed, it was also possible for assessments that were intended to be used formatively, to end up being used summatively. This occurred at Moorgate Secondary College, where a teacher noted that this sometimes happened if a student's performance in the final exam was unexpectedly poor. In such cases, the teacher used formative assessment data to justify their view that the student's examination result was not reflective of their achievements.

4.8.1.2. Grading Characteristics and Granularity

Irrespective of whether an assessment was intended to be used summatively or formatively, it was possible for the feedback to the student to assume many forms. The classification of this characteristic ranged from not being individually graded at all, a circumstance that was observed to occur at both St Johns Wood Catholic College and Moorgate Secondary College when informal diagnostic assessments were conducted in class, to feedback-only responses, pass/fail assessments, letter grades, and so on, through to individual half-marks awarded through a rubric. Indeed, it was seen that online quizzes such as Kahoot! could exhibit even more fine-grained marking than many examinations, since the online tool also considered speed of response for individual questions.

The granularity of the marking scheme also manifested through ranking - a circumstance that subtly changed the effect of the grading. While competitive ranking was invariably based on the same kind of grading criteria as might be used for mark assignation, it was evident that student perceptions of what might constitute valued learning, was sometimes more skewed towards competitive notions of achievement. Such an attitude was observed in several different situations, including Holly's Year 9 class at Farringdon High School, which was the last of six 5.3 classes (out of 10 classes) in a demographic that valued academic achievement; and indeed Holly noted that her students felt fortunate that they had made it in to the 5.3 cohort, and worked hard to maintain their position in the grade. A different manifestation of the effects of ranking was particularly notable at Osterley High School, where students appeared to care little about their grades so long as they reflected their own sense of achievement relative to other students in the grade. In both cases, students appeared to benefit from grading well relative to their peers, rather than comparison against objective outcomes.

4.8.1.3. Fairness, and Considerations of Cheating

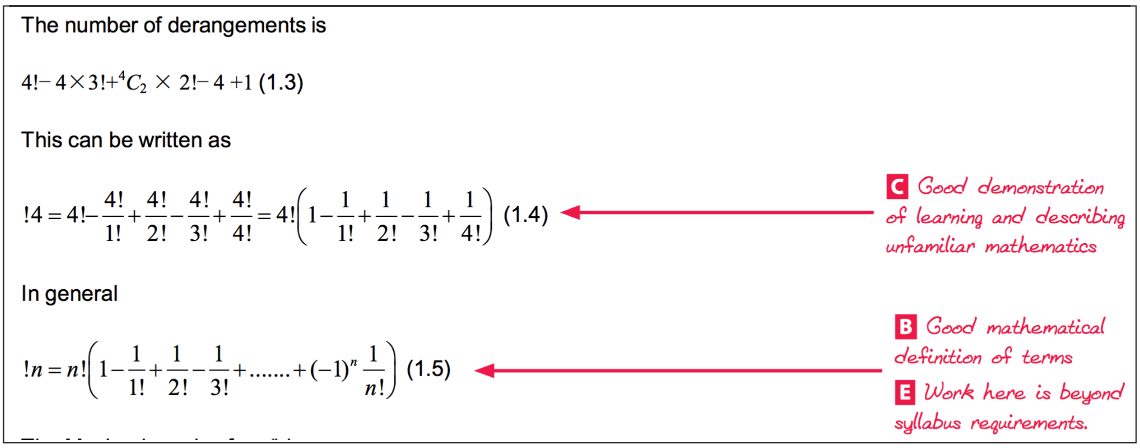
As one of the more contentious aspects of assessment practice, invigilation and the detection of academic misconduct could not be ignored for any summative assessment task. Consideration of the potential for students to cheat, and any structures put in place for managing misconduct, must therefore be included for the purposes of analysing assessment practices.

With behaviours that fall into this category ranging from overt copying and plagiarism, to the potential for group submissions to comprise an unfair distribution of student effort, it was evident that one reason for preferring the examination as an assessment mechanism was simply because it tended to avoid accusations of misconduct. This consideration was particularly noted by Philip at Bermondsey College, where projects were removed from the assessment schedule for students in Years 7 - 10 because the resulting student work did not appear to reflect the students' achievement levels. For the IB Mathematics Exploration, procedures for mitigating such misconduct included allowing students class time to complete assignment work, grading assignments in stages, and post-submission actions such as using plagiarism detection software.

With limited experience in managing project-based assessment, Daniel at Elm Park High School discussed his concerns regarding how such assessments could be managed so that academic misconduct would not occur. It was therefore interesting to note that misconduct was not even canvassed during the interviews at Moorgate Secondary College, where the assessment schedule comprised the highest ratio of project-based assessments of all of the case study schools. It appeared that the culture of the school played a significant role in how students viewed their work; and with students at Elm Park driven by high assessment results, and student work at Moorgate valued for its appropriateness for the individual student, there were indications that cheating would only be an issue within a culture of comparison.

4.8.1.4. Adherence to Class Content

While, under normal circumstances, the schools tended to assess content that was explicitly taught, there were some assessments that departed from this procedure. For example, Farringdon High School assessed the "capture-recapture" question in reverse, an occurrence that caused some consternation for Holly when she taught a lower-ability class. At Elm Park High School, Daniel recognised that the HSC included questions that tested for ingenuity beyond what would be considered to be strict adherence to the syllabus, and deliberately trained his students to look for these characteristics in the questions. In yet another instance where it was beneficial to have studied beyond the standard coursework, the International Baccalaureate Organisation [IBO] offered a work sample which was graded in such a way as to demonstrate the potential for further credit to be awarded for mathematics that was off the syllabus (Figure 4.21); and indeed, perhaps the most striking example of assessing untaught content was Chesham House's Year 7 assessment task involving an external vendor (Appendix A-17).


The number of derangements is

$4! - 4\times 3! + {}^4C_2 \times 2! - 4 + 1$ (1.3)

This can be written as

$!4 = 4! - \frac{4!}{1!} + \frac{4!}{2!} - \frac{4!}{3!} + \frac{4!}{4!} = 4!\left(1 - \frac{1}{1!} + \frac{1}{2!} - \frac{1}{3!} + \frac{1}{4!}\right)$ (1.4)

In general

$!n = n!\left(1 - \frac{1}{1!} + \frac{1}{2!} - \frac{1}{3!} + \dots\dots + (-1)^n \frac{1}{n!}\right)$ (1.5)

Figure 4.21. Sample IB Maths Exploration using content beyond syllabus requirements. (IBO, n.d.a)

The inclusion of assessments of untaught content was particularly interesting because it questioned the implicit assumption that teaching and assessment are "different sides of a single coin" (Harvey & Bright, 1991). Thus, when such assessments occurred, questions arose regarding the skills that may be needed for the assessment, but not necessarily taught in class. These may include (for example) problem solving, collaboration, report-writing skills, resourcefulness, and creativity. Indeed, the inclusion of the skill in the assessment task tended to imply an expectation that, while the skill itself was valued, it was through engagement with an assessment task, rather than through explicit teaching, that the development of the skill was expected to be more readily promoted.

With potential for links between assessment and pedagogy to be disrupted, it was notable that the disruptions tended to occur in schools where assessments were, on the whole, more examination-based. In particular, Moorgate Secondary College, which demonstrated a philosophical position encompassing innovative pedagogy and assessment, appeared to strive to expose the students to all of the relevant skills before they were summatively assessed. There was, therefore, a sense that the assessments that sought to judge students' resourcefulness were employed in situations where resourcefulness in learning was promoted to a lesser degree.

4.8.1.5. Entry and Exit Points

It was evident that most assessment tasks exhibited considerable flexibility with respect to exit points; indeed, traditional assessment mechanisms such as examinations would normally offer students an opportunity to demonstrate their achievement, in such a way that their result is unlikely to be identical to that of another student. However, the case studies demonstrated how it was also possible for assessment tasks to be structured such that entry points may vary, and for exit points to be divergent.

This situation was particularly observed at Moorgate Secondary College, where students were offered a series of assignment “task cards” that demanded different levels of aptitude and engagement with the course content. With the choice of task card being left largely up to the student, the choice of task was itself a revealing symptom of the student’s confidence in their own ability. It was also interesting that the task cards, while offering considerable choice in how to engage, nevertheless all covered similar material - thus ensuring that, while students might have different entry points, their exit points would converge upon a common understanding.

While the specification of the task card assignment did raise questions regarding how it would be marked - that is, whether the flexibility of the assignment needed to be taken into consideration for any grading that might need to occur, such a consideration did not appear to be an issue for Moorgate Secondary College. With a focus on student self-assessment and grading practices that were aimed more towards formative rather than summative assessment, Moorgate maintained a stance that positioned internal assessments as a pedagogical tool, rather than as a summation of students’ achievements. Such a stance gave Moorgate the freedom to use assessment as a differentiation mechanism to support the learning of students with different levels of mathematical achievement.

4.8.2. Categories of Pedagogy and Assessment

Given students’ propensity to value what is assessed, it would be salient to consider how the assessment tasks impacted upon the implementation of the learning activity. The situation at this point can be broken down into four basic combinations, corresponding to the employment of teacher-centric or student-led pedagogies, and traditional or innovative assessment. For the purposes of this discussion, we shall here define “teacher-centric” pedagogies as being those which are actively taught by the teacher - for example, through direct instruction and teacher-led example. This would contrast with student-led learning, which would likely be more exploratory and potentially collaborative in nature; in such circumstances, the teacher would be facilitating the students' own efforts to construct their own understanding. The categorisation of this learning would be represented as a continuum, with student-centred mobile learning occupying positions somewhere in between the two extremes, for even though the mobile device is under the student's control, the activity may or may not place the student in a position where they have control of the learning.

With respect to the categories of assessment, we shall here consider assessment methods that do not exclusively involve work that is silent, solitary, timed, and identically specified for all students, to be in some way novel. Thus, traditional assessment methods would be something akin to examinations, as we currently understand them; and assessment methods that deviate from this structure - including, but not limited to, presentations, projects, or learning activities that produce an assessable outcome, would tend towards the innovative.

The dual nature of this categorisation lends itself towards a two-dimensional representation, as shown in Figure 4.22.

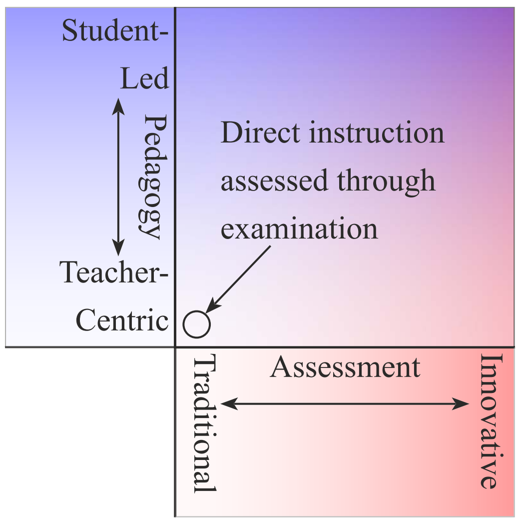


Figure 4.22. Categorisation of pedagogies, and the mechanisms that are used for assessing the learning.

4.8.2.1. Teacher-Centric Pedagogies, Traditional Assessment

Although the general case must be the teacher who would teach in a traditional way, and who foresaw traditional summative assessment techniques being used, the teacher's involvement in this study necessarily meant that they were mobile pedagogical practitioners. Thus it was interesting to note that all of the case study schools employed both traditional pedagogy and traditional assessment. While other teaching methods and other assessments were variously employed at these schools, it was yet the case that direct instruction formed the basis for many of the lessons, and many assessments took the form of traditional examinations. Indeed, for Holly at Farringdon High School and Daniel at Elm Park, it was apparent that all assessments were tests, and at Elm Park, student-centred mobile pedagogies were only employed on rare occasions, if at all.

As a finding that should do little to challenge the status quo regarding what is valued in mathematics education, it is useful to have observed this pattern of usage. It demonstrated that student-centred mobile technology could be used in a way that would enhance instruction without negating cultural assumptions, or relinquishing wisdom acquired through long experience of mathematical pedagogy. Such mobile pedagogies could therefore serve as a gateway for teachers who are doubtful regarding the potential of mobile learning for improving students' learning experiences in mathematics.

4.8.2.2. Teacher-Centric Pedagogies, Innovative Assessment

There were also some case studies that featured, in combination, alternative assessment methods supported by direct instruction. As an example, Osterley High School combined structured teaching sequences with guided project work; and at Chesham House, Patrick described a Year 8 assessment conducted as a lesson presentation, a task that he felt the students "didn't enjoy". However, perhaps the most notable example of this combination was the "Tutorial Blitz" method at Moorgate Secondary College, which saw students engaging simultaneously with textbook exercises and project-based assessment. Indeed, assessments at Moorgate were designed to be particularly student-centric, with students encouraged to submit work that was uniquely theirs:

> They might have to produce a report, or they might produce something, but it might not be on what we necessarily suggest, as long as it's related to the overall topic .... Yeah so long as they still tick off our success criteria, what we've got to assess for, if they can add to it, we certainly encourage that. Make it their own in some sort of way. (Simon, MSC5 0:02:14)

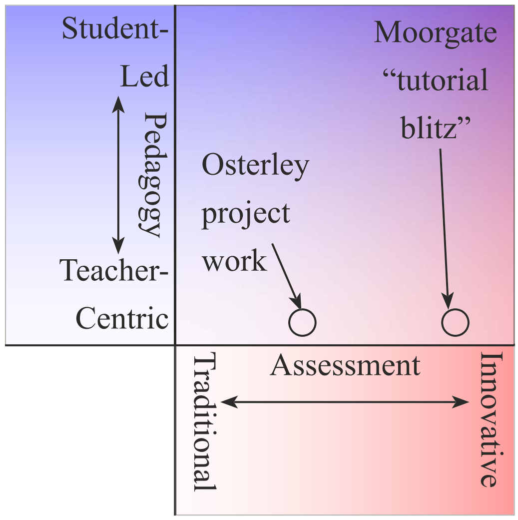


Figure 4.23. Teacher-centric pedagogies combined with non-traditional assessment.

Combinations such as these provided indications of the characteristics of pedagogy that would be required for learning to have a better chance of success. In such cases, it could be inferred that the teachers considered teacher-centric methods to be superior for the purposes of giving students the knowledge and understanding they would need to approach the assessment task. Such a finding was particularly telling because it implied that, despite the novel nature of the assessment method, the skills required to attempt it were not different enough to warrant a change in pedagogy; or indeed that, despite the inclusion of some student-led learning, the teacher had decided that traditional teaching was still required.

4.8.2.3. Student-Led Pedagogies, Traditional Assessment

The alignment of student-led learning with examination-style assessment would tend to indicate that the teacher had some confidence that their student-led learning activity was effective for acquiring examinable skills. Such a reconciliation of student-led learning with traditional assessment was observed to some extent at Chesham House, where Patrick set a Desmos Marbleslides activity for his Year 9 students. Although the activity had been initiated by the teacher, the subsequent learning was mediated by technology that was controlled by the students - a circumstance that suggested that it was, indeed, possible for student-led mobile learning to be valued through an assessment mechanism that is both well-understood and highly defensible.

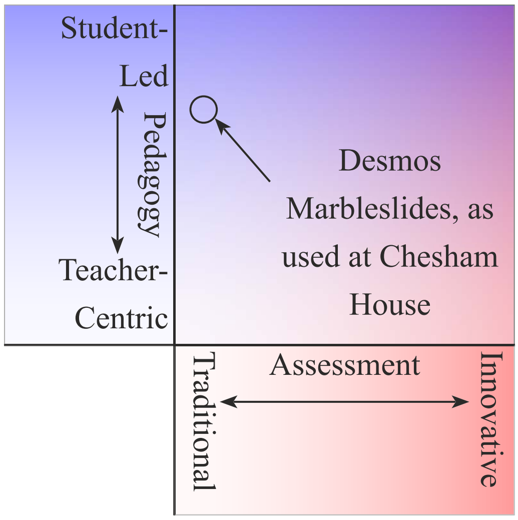


Figure 4.24. Student-led pedagogies with traditional assessment.

4.8.2.4. Student-Led Pedagogies, Innovative Assessment

Finally, the combination of student-led learning with innovative assessment was particularly interesting for its potential to offer some insight into assessment methods that have, perhaps, been invented in order to allow students to demonstrate their learning in different ways. Such a combination was evident in the IB Mathematics Exploration task, which Philip at Bermondsey College considered to be a learning opportunity that would help to develop skills that students would need for the rest of their lives. With student ownership being integral to the task, the pedagogy in this case would initially comprise little more than guidance for the student in choosing some mathematics to research. The student was then expected to use any available methods, including but not limited to technology, to produce an assessable artefact; and, indeed, the teacher's role in this teaching and learning experience was mainly to assess the student work, both formatively and summatively.

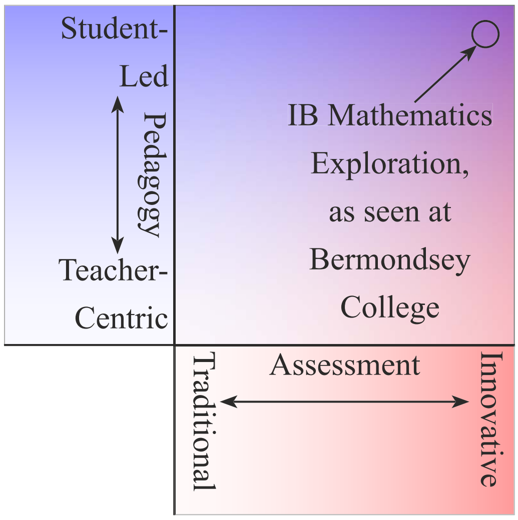


Figure 4.25. Student-led pedagogies combined with innovative assessment.

While mobile technology was not particularly specified for engagement with this task, observations of Philip's Year 12 students working on their submissions during class time demonstrated that all of them used their laptops in the production of this report. Indeed, it could be inferred that the lack of guidance regarding mobile device usage was functionally equivalent to suggesting it as a valid and useful affordance.

4.8.3. Streaming Practices

The relationship between pedagogy and assessment also manifested in the influence of assessment upon streaming. Despite considerable differences between schools with respect to both pedagogy and assessment, streaming was a practice that was observed to be present at all of the schools in some form. A summary of the schools' streaming practices for mathematics in Years 7 - 10 is shown in Table 4.2.

With considerable diversity in how the streams were arranged, it was nevertheless the case that students were invariably placed in streams based on their results in some kind of summative assessment. The relationship between assessment, streaming, and pedagogy

Table 4.2. Streaming Practices for Junior Mathematics at Case Study Schools.

Bermondsey College	• Years 7 and 8 streamed for top two classes, two mixed-ability classes, and (if required) one small low-ability class. • Two 5.3 classes and two 5.2 classes for Years 9 and 10, all streamed.
Chesham House	• Always streamed for top class and bottom class. • Middle classes may be streamed or mixed.
Elm Park High School	• One class of 30 students who need help with algebra. • One class of 30 students who need help with geometry. • Two further classes, split based on raw examination results.
Farringdon High School	• Fully streamed from Year 8, with two classes per stream. • Access to 5.3 and 5.2 curricula determined by stream.
Moorgate Secondary College	• Some streaming of the top students from Year 9 onwards. • Year 7 and Year 8 classes mixed.
Osterley High School	• Streamed. Strict cut-offs for classes based on examination results. • Students with the same mark ranked alphabetically.
St Johns Wood	• Streamed for top class and bottom class. • Middle classes are mixed.

was therefore causal; after students were placed in streams based on their assessment results, each streamed class was exposed to pedagogy that was considered to be suitable for its level of attainment.

The relationship between streaming and pedagogy was perhaps most strikingly emphasised at Elm Park High School, where assessments were used as a diagnostic tool to place students in classes for remediation in Algebra and Geometry. It could also be seen that streaming practices at Farringdon High School and Osterley High School were strictly enforced with reference to students' relative ranking in a summative assessment, and in the case of Farringdon, components of the pedagogy were likewise strictly limited to students who were in the 5.3 stream, and so on.

4.8.4. The Importance of Work Ethic

In discussing the importance of different skills for the demonstration of mathematical competence, patterns emerged that showed a disconnect between the skills required for mathematics assessments and the skills required for life after school. It was perhaps unsurprising that, for example, being able to solve closed problems (with one correct answer) was considered to be more important for examinations than as a valued life skill in the 21st century. Likewise, it was expected that teachers would recognise the inappropriateness of collaboration in an examination, and that such a skill would be more valuable in real-life situations.

Appendix A-20 includes the responses to the interview questions that were discussed in Section 3.3.1.6 (see also Figure 3.7). There are only four such responses because this prompt was not used at the Project schools; it was also not used at Chesham House, where time limitations dictated a shorter interview. However, in discussing the relative importance of different skills, there were striking instances of concurrence of opinion between the teachers. In particular, all of the teachers noted the importance of comprehension skills (following instructions and deciphering questions) and accuracy, for performance in an examination. Likewise, knowing how to seek clarification and information was considered by all of the teachers to be highly important for mathematics in the real world.

Perhaps the most interesting response, however, was given with respect to the importance of work ethic. Of the four teachers, three rated work ethic as being of the highest importance for mathematics examinations. The fourth response, from Elizabeth at Osterley High School, rated work ethic as being relatively unimportant. Her somewhat surprising answer was qualified with her perspective that students could choose not to care about their results:

> The kids in the low ability classes already have this assumption that they're really stupid at maths. They can't do it. OK. So then they come in to a test, and they're usually not prepared ... [and] they don't do well on the test, but it's an hour of pain. (Elizabeth, OHS1 0:48:37)

Elizabeth's views regarding examinations contrasted with her view that work ethic was required for other assessment tasks, as well as for life after school; and, indeed, it could be seen that all of the teachers believed that work ethic was just as important for their internally set assessment tasks, as it was for working mathematically in real life situations. While the sample size is so small as to render such an observation statistically meaningless, this and other similar results suggest that the teachers believed that, when compared with examinations, alternative assessment methods aligned more closely with the work that would be required for solving mathematical problems in real life.

5. Discussion

You don't see what you're seeing until you see it, but when you do see it, it lets you see many other things.

- Thurston

With an aim of providing some answers for the research questions, this chapter presents one possible interpretation of the research findings. Valsiner's Zone Theory will be used to structure the interpretation, and it will be seen that Zone Theory is flexible enough to accommodate modifications that allow for a more elegant interpretation of the phenomenon being observed, and indeed support a more precise redefinition of the research questions.

The chapter will then be conceived in two sections, in the first of which I propose a response to the first two research questions:

1. What do secondary mathematics teachers value in student learning with mobile technologies?
2. How do traditional mathematics assessments influence teacher perceptions of the effectiveness of teaching with student-centred mobile technologies?

In the second section I will propose a response to the third research question:

3. What do mathematics teachers perceive to be the characteristics of assessment methods that enable and encourage the use of mobile technologies?

5.1. Structure of the Analysis: Valsiner's Zone Theory

As discussed in "2.4. A Theoretical Framework", I propose that Valsiner's Zone Theory would offer an elegant means of conceptualising the results from this study. In particular, zone theory's ability to describe a teaching and learning situation in terms of what is permitted, and what is promoted, offers considerable flexibility for presenting the circumstances under which the teacher operates - both in the sense of being a Teacher-as-Teacher (a teacher of mathematics), and Teacher-as-Learner (a learner of mobile pedagogies and innovative assessment methods).

Valsiner's Zone Theory proposes the existence of three zones, one of which is the Vygotskyan Zone of Proximal Development - the set of actions that would be appropriate for extending the individual's personal capabilities. The Zone of Free Movement (ZFM) is then defined as the set of actions that are permitted in a certain situation; and finally the Zone of Promoted Action (ZPA) defines the set of actions that are promoted in a particular situation. Other sub-zones can then be described; for example, in discussing actions that were apparently classifiable as being promoted but not permitted, Blanton et al. (2005) proposed the existence of an 'illusionary' zone of promoted action (IZ), defined as "a zone of permissibility that the teacher appears to establish through behaviors and routines used in instruction, but in actuality, does not allow."

5.1.1. Applications of Valsiner's Zone Theory

With a framework that facilitates the discussion of influences upon mathematics teaching and learning, it becomes possible to categorise teachers' practice according to their actions, and the relative positions of these actions within the three zones. It must here be noted that there will be, at minimum, two zone representations associated with each teacher. With respect to the teacher-student relationship, the teacher creates an environment for the class which exhibits some combination of ZFM/ZPA. This environment may or may not vary, depending on the students or the nature of the content being taught; but for each teacher, there must be at least one instance of this ZFM/ZPA complex. Its purpose would be to define student actions that the teacher permits and/or promotes.

The second zone representation would describe the teacher's own actions. That is, the teacher operates under certain constraints, and incorporates particular actions into their teaching; this representation is a characterisation of the influences upon the teacher's pedagogical choices. For the purposes of discussing teachers' developing proficiency with mobile pedagogies, this model will serve to define the context for the Teacher-as-Learner.

We shall here assume that, prior to the introduction of mobile learning, the zone diagrams would default to the configurations shown in Figure 5.1 and Figure 5.2. The "fuzzy or indeterminate nature of the phenomena" is here expressed by augmenting the more conventional Venn diagram format with dashed outlines and gradient fills.

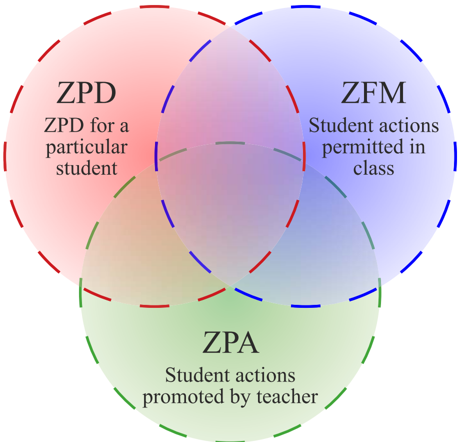


Figure 5.1. Default zone diagram for Teacher-as-Teacher: influences upon a student's actions.

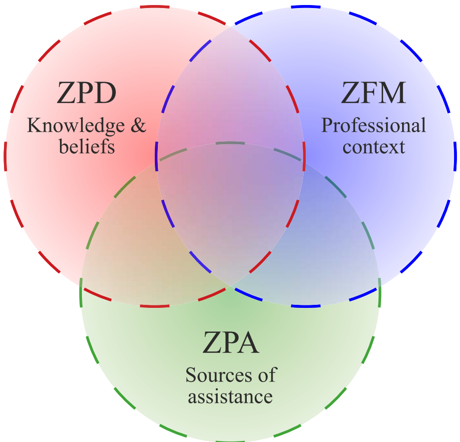


Figure 5.2. Default zone diagram for Teacher-as-Learner: influences upon teacher actions. (Adapted from Goos, 2008)

However, with reference to the zones created by the Teacher-as-Teacher, it is evident that the introduction of mobile technology into an educational setting introduces the idea of a Zone of Free Movement that is enabled by the technology, and which we will henceforth refer to as the M-ZFM. As observed in the case study schools, the students' mobile devices each offer a means of accessing virtual environments that transcend the physical limitations of the classroom, thus effectively expanding each student's total Zone of Free Movement (Figure 5.3).

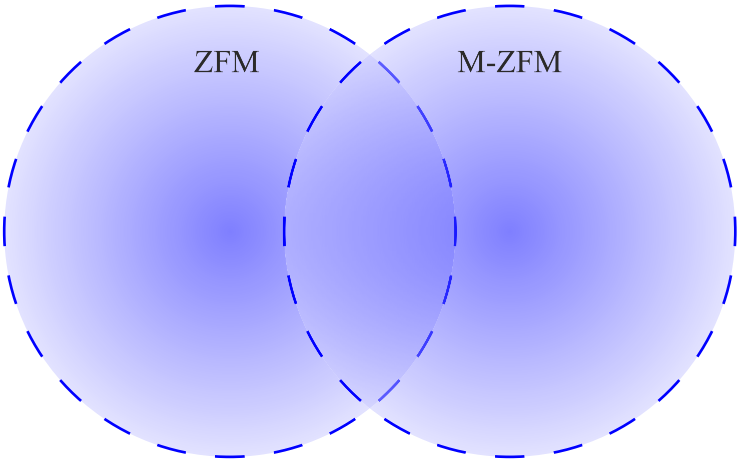


Figure 5.3. A representation of the zone change that occurs when mobile learning is introduced.

With an area of overlap representing classroom-based mobile pedagogies, the Zone of Promoted Action for the Teacher-as-Teacher would then straddle all three areas (Figure 5.4).

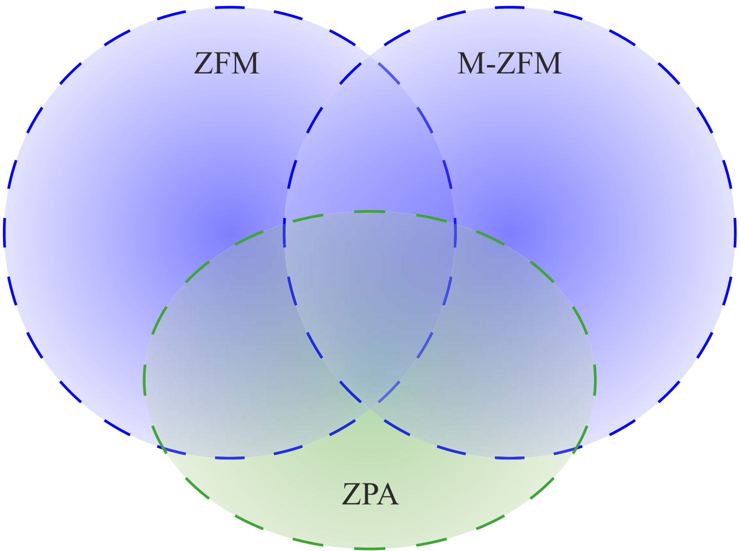


Figure 5.4. A default ZFM, M-ZFM and ZPA configuration for the Teacher-as-Teacher.

We have arranged the zone configuration so that it is possible for an Illusionary Zone of Promoted Action (IZ) to exist - since, as argued by Goos (2008), the implementation of innovative pedagogies sees teachers in a Teacher-as-Learner situation:

> while the ZFM suggests which teaching actions are *allowed*, the ZPA represents teaching approaches that might be specifically *promoted* by pre-service teacher education, formal professional development activities, or informal interaction with colleagues in the school setting (p. 237, emphasis in original)

and so, in trialling innovative pedagogies, there may be inconsistencies between what the activity promotes, and the teacher's own ideas for how the content should be taught.

Finally, there may be components of each student's Zone of Proximal Development which would exist in each of the identified areas (Figure 5.5).

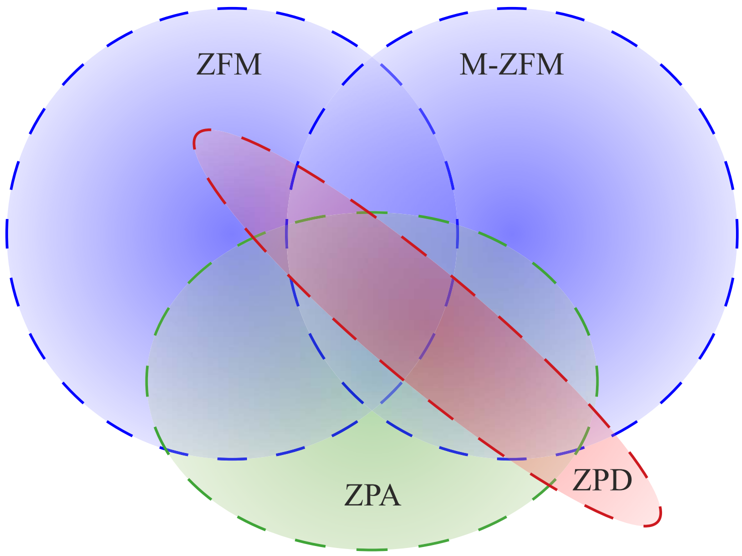


Figure 5.5. A default ZFM, M-ZFM, ZPA and ZPD configuration created by the Teacher-as-Teacher.

This augmented diagram of the zones of influence acting upon an individual will serve as our base representation for the Teacher-as-Teacher - that is, the environment that the teacher creates in the classroom. It is notable that, while the IZ itself is not excluded, the diagram does not define whether a factor in the IZ would only exist following the advent of the M-ZFM. This limitation could have been addressed by redefining the ZPA as a ZPA/M-ZPA combination, which would be roughly analogous to the ZFM/M-ZFM. However, this omission is not currently significant for the purposes of describing the environment created by the Teacher-as-Teacher.

5.1.2. Defining the Research Question in terms of the M-ZFM

Since the present study seeks to describe the implications of mobile learning for secondary school mathematics assessment, and vice versa, we shall now more precisely define the nature of the problem as being related to the introduction of the M-ZFM. Accordingly, we can now represent the research questions as follows:

1. What do secondary mathematics teachers value in student learning that is enabled by the presence of the M-ZFM;
2. How do traditional mathematics assessments influence teacher perceptions of the effectiveness of teaching with the M-ZFM; and
3. What do mathematics teachers perceive to be the characteristics of assessment methods that permit and encourage the presence of the M-ZFM?

In considering the first two questions, we shall examine the factors that are involved in the decision to promote or withhold student-centred mobile technology use in class. We shall evaluate the circumstances under which the M-ZFM is introduced, and the role that is played by mathematics assessment in making these decisions.

The last question requires reflection regarding the value of mobile learning for the teaching and learning of mathematical skills. In particular, we shall consider how we might appraise mathematical skills that are supported by the use of mobile technology, and the implications of having the M-ZFM present while a mathematics assessment is being conducted.

5.1.3. Considerations of Formative Assessment

The practice of using mobile technology to gather diagnostic information, and thus support formative assessment, was noted in a number of the case study schools. However, in attempting to apply the present theoretical structure to the analysis of this practice, it became evident that the fit would be poor. That is, in considering influences of mobile technology upon formative assessment practices, the use of the proposed framework does not present any new perspectives, or illuminate any unresolved issues.

The question of whether the present study should be concerned with formative assessment may be answered by considering practices that were employed at the case study schools. Mobile technology did, indeed, support formative assessment in a number of situations. Quiz applications such as Kahoot!, and applications such as Desmos and PearDeck for collating student work, were used in many schools to give the teachers indications of topics that needed to be re-taught.

However, it was also evident that this kind of formative assessment could also be carried out without the mobile technology. To circumvent the shortcomings of the wireless network infrastructure at Osterley High School, Elizabeth introduced “Plickers” - an application that offered functionality that was identical to an online quiz, but which only required teacher-centric technology. Philip, at Bermondsey College, conducted his formative assessments with much older technology, preferring to have his students show their responses on small individual whiteboards.

The potential for the technology to support formative assessment can be a compelling reason for introducing mobile technology into the classroom. However, as demonstrated by Elizabeth and Philip, the capabilities that mobile technologies support are neither novel nor irreplaceable. Like electronic textbooks, the use of technology to gather student responses may be convenient - but it does not meaningfully affect the way that teachers teach, or the way that students learn.

In terms of the theoretical framework, actions that collect formative assessment data are Promoted Actions that exist in both the ZFM and the M-ZFM. It may therefore be argued that, since teachers who wish to conduct formative assessments could do so with or without the M-ZFM, the introduction of the M-ZFM has little effect upon the action of formatively diagnosing student difficulties. We shall therefore abandon this line of enquiry in favour of relationships that demonstrate stronger links.

5.2. The Influence of Mathematics Assessment upon the M-ZFM: Streaming

In the case study schools, it was found that classes were, more often than not, streamed to some degree; and the objectivity of the exercise was maintained through reference to the results of summative assessments such as examinations. Since ability grouping gives greater opportunities for catering to each student's unique Zone of Proximal Development, Vygotskyan theories of student development present a compelling argument in favour of this particular pedagogical strategy.

5.2.1. Streaming Practices in the Case Study Schools

In the case study schools, the existence of streaming allowed the teachers to conceptualise their expectations for the class in a more general fashion. It tended to change their description of a teaching situation in such a way that they would discuss the class as a whole, rather than describing individual students. In particular, the case of Chesham House was striking for Patrick’s experiences of teaching both streamed and unstreamed classes, and it clearly demonstrated that teaching an unstreamed class was a far more complex endeavour:

> Streaming, definitely, I think has a big impact on how you do things. I’m teaching once a fortnight, a Year 8 STEM class. I’ve got students in there who are in the weakest mathematics group with very significant behavioural issues, and I’ve got students who are at the very top of the mathematics group as well. And trying to pitch a lesson at them, is extremely difficult. (CH1 0:26:46)

While all of the case study schools engaged in streaming for mathematics classes, there were variations in implementation, with some schools choosing to stream all classes, and other schools preferring to minimise the number of students who were deliberately selected for inclusion in a particular class. Indeed, for schools such as Moorgate Secondary College, it is notable that teachers chose to stream at all. With pedagogy designed around a differentiated assessment structure, Moorgate demonstrated a considered philosophical stance regarding student achievement, whereby teachers would design curriculum that allowed students to choose the level at which they felt they should be working, and students would be supported irrespective of their choice. The fact that Moorgate ended up creating a top class for Year 9 Mathematics tends to suggest that ability grouping can be seen to be necessary, even when the school has gone to great lengths to provide a unified learning experience that aims to cater for all.

Another notable streaming implementation was observed at Elm Park High School, which changed its streaming practices from a fully meritocratic ranking scheme to ability grouping for assessed mathematical weaknesses. Students who performed poorly in algebra would be assigned to one class, and students who performed poorly in geometry would be assigned to another. The purpose, in this case, was to recognise that algebra and geometry were both fundamentally important for mathematical understanding, and that students would benefit from intensive remediation of the facet of mathematics that they found challenging.

5.2.2. Streaming and Mobile Technology Use

In considering the influence of assessment on pedagogy, the existence of streaming necessarily indicates that assessment has occurred, and that the results of the assessment are being used to place students in particular streamed classes. The implication is that the teacher would then be better able to take the students' ability levels into consideration when planning lessons.

Therefore, with the link between assessment and streaming being not merely correlative but in fact directly causal, it is significant that, in the case study schools, all of the interviewed teachers tended to promote the use of student-centred mobile technology with higher-ability classes - that is, the higher-ability classes' use of mobile technology universally matched or exceeded its use in lower-achieving classes (Figure 5.6).

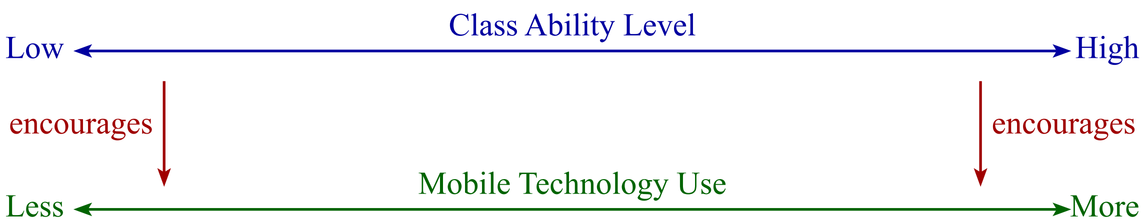


Figure 5.6. Relationship between Class Ability Level and Mobile Technology Use.

This relationship is particularly noteworthy when we consider that the technology usage patterns were similarly affected irrespective of the students' "absolute" achievement. While the comparison, for the purposes of streaming, necessarily occurs within a single school, it is perhaps less obvious that the teachers appear to perceive student ability levels as a function of whatever the norm is, in their school. Thus we have a somewhat surprising situation where students who were selected for their academic ability - including high performance in primary school mathematics and achievement in a separate state-run mathematics examination - are nevertheless considered to be underperforming in mathematics, and less suited to engaging with mobile learning (Daniel, EPHS 0:12:23; see Sections 4.6.3 and 4.6.12).

5.2.3. Theoretical Implications of Streaming

With reference to the zone representation, streaming makes some attempt to categorise students according to their demonstrated ZPD.

Figure 5.7 offers a simplistic view in an attempt to illustrate what this might mean for two different students.

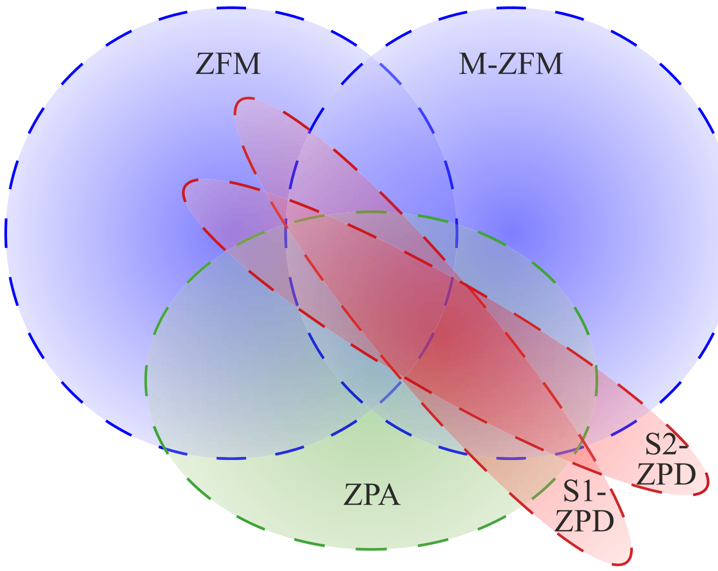


Figure 5.7. Simplified zone representation with ZPDs for two different students.

In such a diagram, the area of overlap between the two students' Zones of Proximal Development would indicate the teaching and learning that would be effective for both - although clearly the representation is oversimplified in this case, as it does not offer regions to represent all possible scenarios. The aim of streaming would be to maximise the area of overlap so that, even with a class of thirty students, each student would hopefully be receiving some instruction that is suitable for their current development.

A similar representation may then amply demonstrate the potential for instruction to be ineffective for some students, particularly when the students are at widely differing stages in their mathematical development (Figure 5.8).

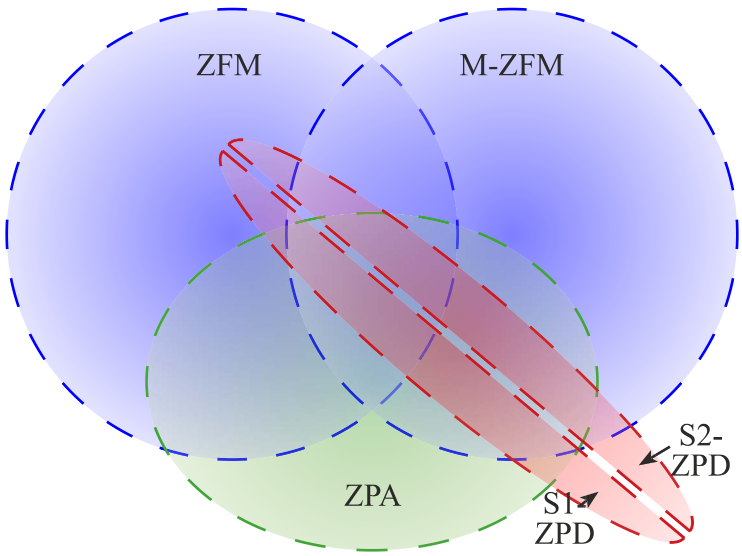


Figure 5.8. Simplified zone representation with ZPDs for two students exhibiting widely different levels of mathematical development.

In the case study schools, the streaming of students appeared to assist teachers with conceptualising learning activities that were appropriate to the class. This did not mean, however, that teachers used it to justify a lack of personalised attention to individual students. Concerns such as those raised by Boaler et al. (1998), who suggest that

> setted [i.e. streamed] lessons are often conducted as though students are not only similar, but *identical* - in terms of ability, preferred learning style and pace of working (emphasis in original)

were not observed to the degree that this would imply; and indeed all of the case study teachers went to significant lengths to run lessons that were inclusive of, and accessible to, all students in their classes.

The employment of mobile pedagogies was, however, observed to vary as a general function of the streaming. Teachers tended to eschew or discourage the use of mobile technology in class when the class was considered to be of lower ability. This correlation was unambiguous; in all of the case studies, it was never the case that a lower-ability class would be encouraged to use mobile technology in a situation where its higher-ability counterpart would not. However, it would be misleading to imply that this correlation applied across school years; and indeed there actually appeared to be two separate sub-relationships, which give rise to separate considerations.

5.2.4. Considerations of Relative Mathematical Achievement

With a direct relationship between assessment results and stream allocation, and a significant correlation between stream allocation and mobile pedagogical adoption, the first sub-relationship may be summarised as shown in Figure 5.9.

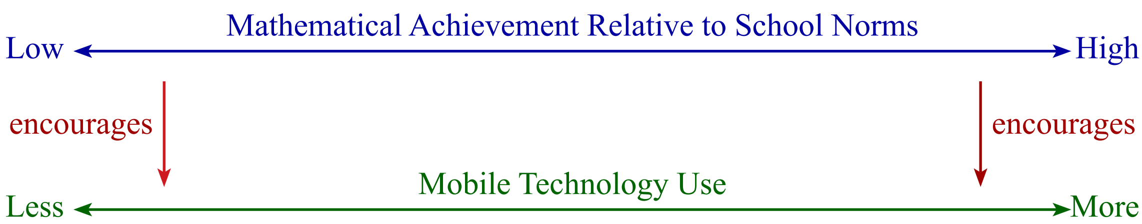


Figure 5.9. Relationship between Mathematical Achievement and Mobile Technology Use.

In some such cases, mobile device usage was deliberately restricted because the technology use changed the nature of the learning activity. For example, it was noted that flat-screen representations of geometrical ideas were confusing for students in a lower-achieving class at Bermondsey College:

> It depends on which level of class you're teaching. That [Geogebra use as a proxy for concrete materials] was with a higher level ability class. I wouldn't do the same with a lower ability class, because using lots of tech with low ability students isn't really great. It's better to actually have concrete devices. Like, literally giving them shapes, and make them cut out nets. (Philip, BC1 0:07:52)

Under these circumstances, the teacher chose to restrict mobile device usage because the technology did not improve access to the sought-after mathematical understandings (Figure 5.10). In some situations, mobile learning presented as being inferior to other available pedagogies; in others, it increased the Zone of Free Movement without offering commensurate benefits over older mechanisms - such as, for access to drill and practice.

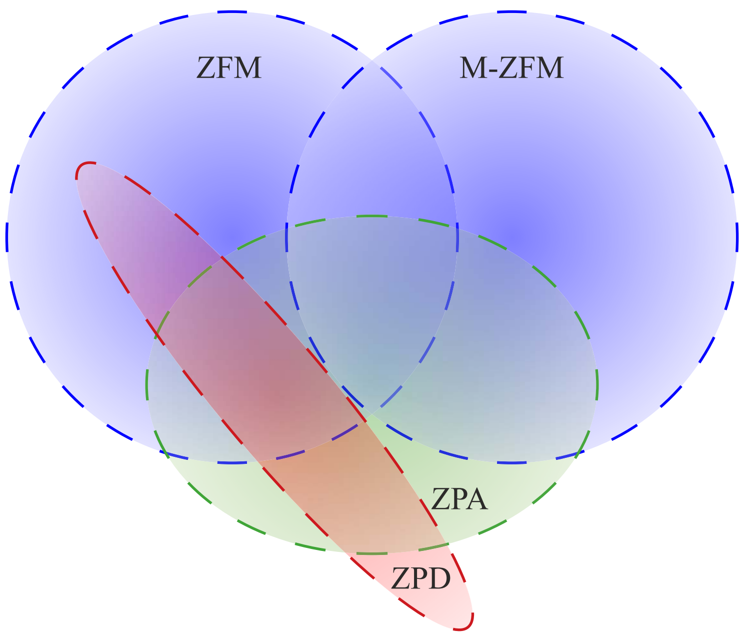


Figure 5.10. Simplified zone representation for the teaching of three-dimensional spatial reasoning at Bermondsey College, with ZPD for a lower-achieving student.

Despite any contention regarding its pedagogical merits, drill and practice was a strategy that was employed with varying degrees of intensity at all of the case study schools. In all of the schools, students were observed being taught methods for solving particular mathematical problems, and then practising problems that shared characteristics with the teacher's example. With an apparent near-universal acceptance of this teaching method, it is interesting to consider the belief expressed by Daniel at Elm Park that students were more likely to complete practice exercises if they were provided in printed form - a view that was informed by prior experience at a boys' school:

> One of the staff members there, who knows - who's now since retired for a couple of years, is never just go online. That particular staff member saw the good things that could be happening online, but he said, "With boys, don't just go online. They're not going to download it themselves." … If you just chuck it online, boys do not go and look at it, unless they're the really toppish lot. Really self-motivated. (EPHS 0:24:15)

While the present exploration of mobile learning does not seek to particularly focus on the use of the technology for the provision of drill and practice opportunities, it is nonetheless significant that Daniel maintains this perspective regarding barriers to using the devices in this way. In his discussion of the relative merits of online content delivery, Daniel deliberately qualified his view regarding the suitability of this delivery mechanism with a categorisation of the students for whom he felt it was more or less likely to work. It is clear that, with a viewpoint borne of experience and corroborated by a colleague, Daniel saw the use of technology for the provision of drill and practice as being less effective for students who are not as motivated to achieve.

With different teachers offering considered judgements that mobile learning was less beneficial for lower-achieving students, an extreme zone configuration for lower-achieving classes would then tend towards the configuration shown in Figure 5.11.

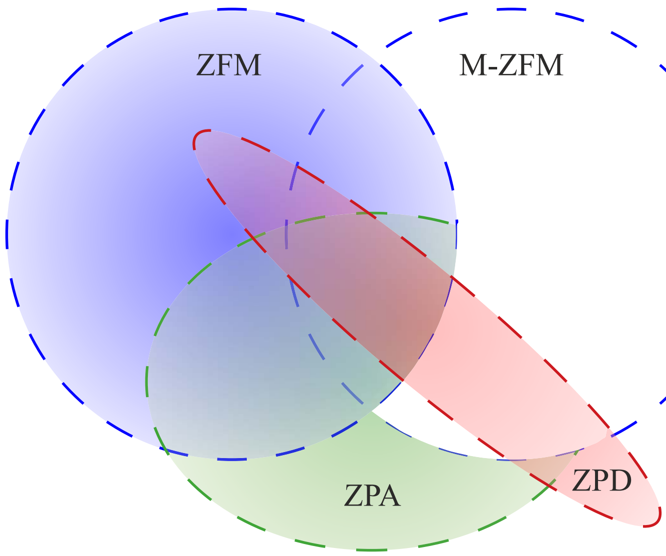


Figure 5.11. A ZFM, M-ZFM, ZPA and ZPD configuration when mobile technologies are not permitted in the classroom.

While it is possible for such a configuration to occur, due to the nature of the observation request, none of the observed classes exhibited this arrangement. Since observations had been scheduled for classes that did engage with mobile pedagogies, there were none conducted in classes where mobile device use was proscribed.

It is therefore interesting to note that lower-ability classes did, nevertheless, figure in the observation schedule. Of these, perhaps the most extraordinary was the Year 9 special needs class at St John's Wood Catholic College. Students in this class engaged with a modified curriculum, and lessons were conducted in a manner that was clear, direct, and prescriptive. Despite the teacher's evident experience with both the class and the use of mobile technology, delivery of the lesson content through the mobile device was complicated by the difficulties that students experienced when trying to log in to the

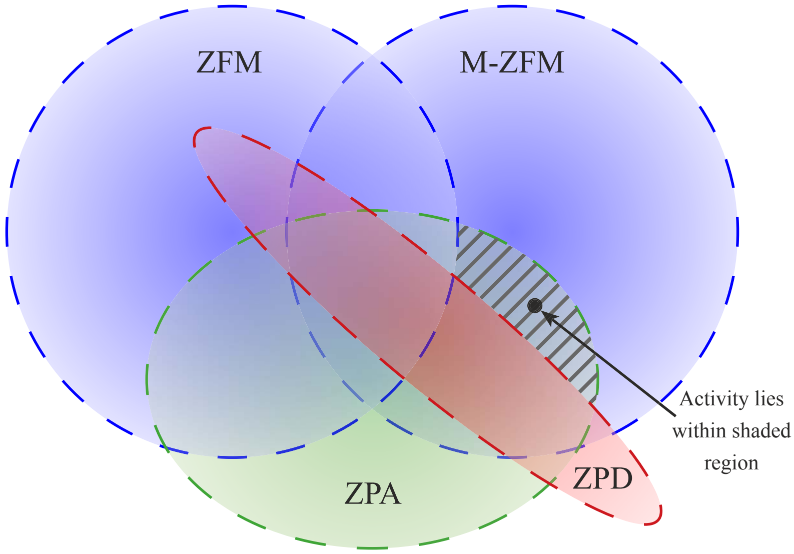


Figure 5.12. Positioning an assignment activity delivered through Moodle, for a special needs class.

learning management system. Indeed, in a subsequent interview, the teacher described the practical issues that arose from the extra layer of complexity that mobile device usage inevitably introduced (Figure 5.12):

> We have the assignment for them to complete. And it was uploaded on Moodle and [the students] were asked to complete it and hand it in by a certain date, and I struggled actually to collect most of it by the end. So, and the second time around I decided just print it and they can complete on paper … and that's when I actually had everyone's. The first time around, when I actually had [it] on Moodle, I struggled. (Martha, SJW3 0:04:10)

This was then contrasted against the affordances of technology for students in that class:

> I can pretty much use visuals, for those students that are unable to read … it reads for them. I actually have one student in my Year 9 class that's like that. He's unable to write and read properly. So most of the time he watches videos. Or gets the iPad to read to him … To complete an assessment, [when] he reaches a question, I'm not giving him the answers. I'm showing him a video, he will watch

it, explain what he understood from it, after which he's actually given a mark. (Martha, SJW3 0:20:10)

From the teacher's comments, it may be inferred that the Moodle activity saw a misalignment between the ZPA and the students' ZPD, while the assignment for the student who was unable to read offered an example of a learning/assessment activity that the mobile device makes possible (Figure 5.13). There is, therefore, some indication that the point of difference is not so much in the device usage as it is in the nature of the activity. That is, the M-ZFM makes aspects of the student's ZPD accessible, but the ZPD must be considered if the mobile pedagogies are to have a positive effect.

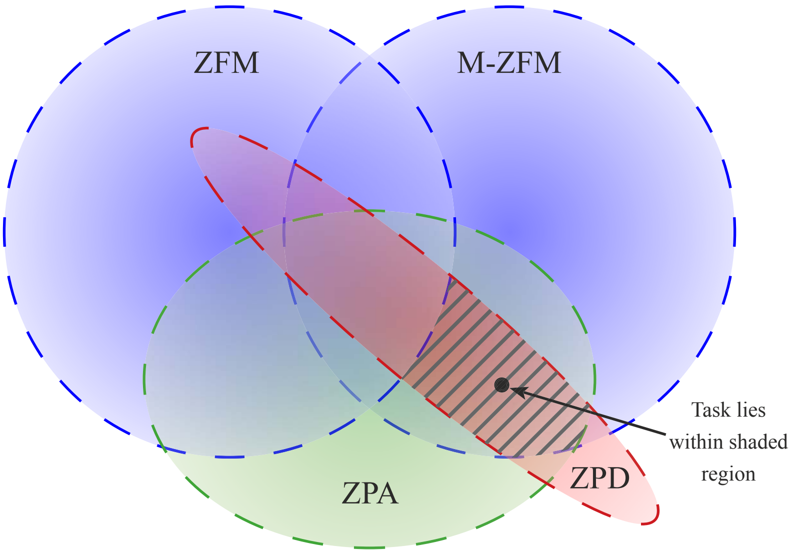


Figure 5.13. Positioning an iPad-enabled assessment task for a student who could not read or write.

In considering the issue of streaming for mathematical ability, it is apparent that the teacher's capacity to make generalisations about the ability level of the class is highly relevant to the way in which the mobile technology is used. There are evidently circumstances under which mobile learning may be considered to be particularly beneficial or, alternatively, inappropriate. Indeed, any mobile learning activity may be conceptualised as being within

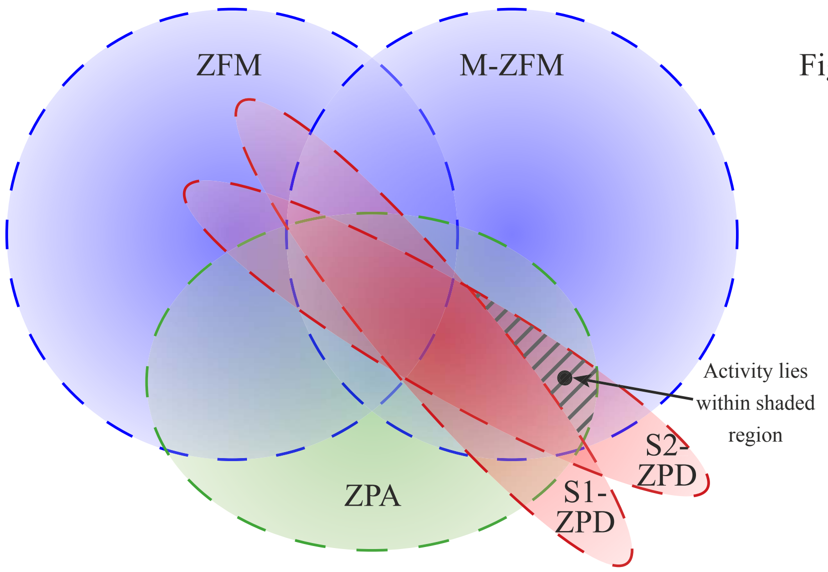


Figure 5.14. Positioning a mobile learning activity that is developmentally appropriate for S2 but not for S1.

the ZPD for one student, but unsuitable as a learning activity for another (Figure 5.14). The employment of streaming strategies is just one heuristic mechanism that aims to give all students access to learning that is, for them, developmentally appropriate.

5.2.5. Considerations of Behavioural Maturity

At the case study schools, the choice to discourage or limit mobile device usage was, in many instances, attributed to students' lack of social maturity. In discussions of this issue, it was notable that the device was rarely presented as a cause of misbehaviour. Rather, the perspective offered by the teachers was that students needed a scaffold through which they might learn device-use etiquette and self-restraint (Figure 5.15).

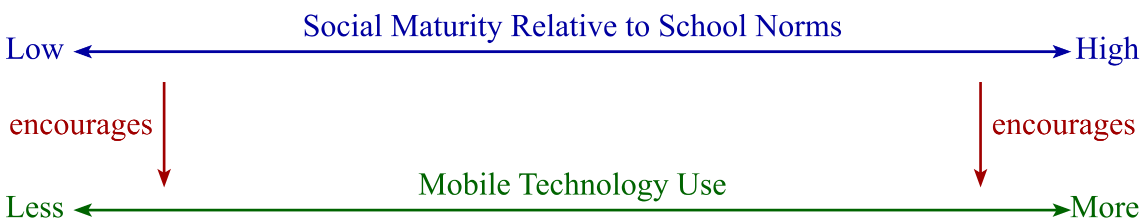


Figure 5.15. Relationship between Social Maturity and Mobile Technology Use.

In situations where devices were present but judged to be inappropriate, schools and individual teachers developed protocols that would restrict student device usage, and each teacher handled classroom management concerns in a slightly different manner. The challenge inherent in managing students so that they would work productively with mobile devices was particularly explicated by the teachers at Moorgate High School, which runs a program whereby all students would be expected to have an iPad for school use:

> Certain kids find it really difficult to work with that sort of technology … In the independent learning time, we've got some kids that have got those iBooks that we were talking about, printed out. So they've got it hard copy. They're the kids that, if their iPad is in front of them, they can't just sit. … Some classes, you know, "iPad, on a pile. We're all working pens and paper, we're not even going to touch them today." Because they are students, and they do need that scaffold. But then obviously our goal is that they can be productive while [distracting technologies are present]. (Scott, MSC4 0:14:38)

What was particularly significant, however, was that there appeared to be an accepted correlation between demonstrated mathematical achievement, and the ability to access mobile learning with discretion and self-restraint. That is, in circumstances where device use was proscribed or discouraged because students were acting in an immature fashion, the perception was that the immature behaviour was exhibited by students in lower-ability classes:

> With the top classes, it wasn't really much of an issue, but the bottom class, they started putting stupid names into their aliases. So, it's behavioural. (Daniel, EPHS 0:14:28)

> With the mixed ability, for some of them anyway, some of them have short attention spans. They'll lose it as soon as they're not able to do something. Pretty soon they'll start chatting … they'll start fidgeting around and just not doing the right [thing], you know, obviously I have to constantly remind them. But with my top class, even if I turn around they'll still be doing the right thing. And if they finish, they'll tell me - "Done". (Martha, SJW3 0:18:19)

Indeed, in an instance of "the exception that proves the rule", Patrick at Chesham House demonstrated insights into how mobile learning can actually assist with behaviour management:

> Behaviour management was an issue with them, and I'm not having to manage their behaviour. Because I can stand at the back of the room and say, "You've got two options. You're watching, or you have your textbook open." … And that meant that the students who were a little bit slower, and maybe who didn't have the right attitude, were not impacting the students who wanted to do the right thing, as much. (CH1 0:13:07)

Patrick's thoughts regarding mobile technology in class were particularly revealing for their insights into the unequal nature of mobile learning for students who exhibited different levels of regard towards their education. It appeared that, in his experience, mobile learning was of more benefit for students who had "the right attitude":

> There were three or four students in there who really didn't want to be on task at times. So for them, much of a muchness, perhaps. But, for the students who wanted to be on task - I think they had a much greater opportunity to be on task. (CH1 0:14:09)

While the reasoning behind this heuristic classification of students' social readiness for mobile learning was evidently based on classroom experience, there is some suggestion that there does exist a measurable correlation between social maturity and academic success. This is particularly apparent when we consider Greenberger and Sørensen's formulation of a framework to specifically measure and value social maturity (Greenberger & Sørensen, 1974). While the framework deliberately distanced psychosocial development from academic achievement, it is notable that Greenberger's subsequent work describes how "psychosocial maturity is itself significantly related to school success" (Steinberg et al., 1989).

Although there is no suggestion that such a relationship between social maturity and mathematical achievement invariably holds true for an individual, it would be reasonable to assume that the existence of a correlation, however slight, can change the classroom dynamic. In particular, it can be seen that the social nature of classroom interactions restricts the teacher's ability to enforce different ZFMs and ZPAs for different students. With two hypothetical classes, the class with comparatively high numbers of behaviourally immature students would generally require firmer management than the one for which such students were few; and the chosen management style would be applied for each class as a whole, even if an individual student did not fit the mould.

As a pedagogical approach, mobile learning is notable for its ability to widen the student's ZFM to include all of the virtual environments that the device renders accessible. The implications of this ZFM expansion must therefore include considerations of what such a change might mean for the management of classes with different characteristics, particularly with regard to the students' behaviour. Thus there are indications that the theoretical implications of endorsing mobile pedagogies are consistent with teachers' actions in a practical context: that is, more care and stricter disciplinary management would need to be exercised for groups of students whose conduct is expected to be more juvenile, and the consequences of an arbitrary increase of the ZFM would need to be considered as a confounding factor for classroom management.

Thus it was interesting to note that, throughout the case studies, there were instances where teachers had formulated partial solutions to this issue. We shall here consider different practices and mechanisms that were employed to manage the ZFM expansion, and the effect each one had on the teaching and learning environment.

5.2.5.1. Temporal Restrictions

In all of the case study schools, the management of device usage incorporated elements of traditional classroom management strategies. The restriction was analogous to “Pens down”, although sometimes the injunction was not specifically phrased to focus on device usage, but simply to direct student attention towards the board.

The employment of this strategy sees the Zone of Free Movement cease to include the use of the mobile device at particular times, as designated by the teacher (Figure 5.16). With this method of management, the zone configuration fluctuates according to the presence and the absence of the M-ZFM.

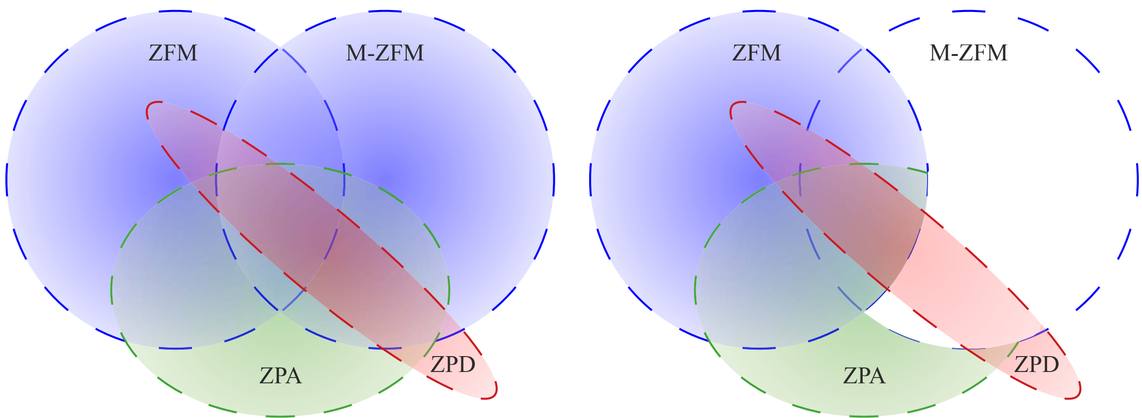


Figure 5.16. Zone fluctuations for temporal restrictions.

Temporal restrictions offered a lightweight method that was easily understood by both students and teachers. Indeed, at St John's Wood Catholic College, a recognition that such classroom management strategies were required led to the institution of a school-wide initiative that is now employed by all teachers:

> That whole thing, though, has got all of them doing "Flip the Lid" - flip the cover. So they know - it's just a little system that they've all been told - I need your eyes up here, or whatever - Just flip the lid. (Matthew, SJW1 0:23:38)

It was found, however, that this method was insufficient for maintaining control, and teachers needed a consistent and unified response for situations where "Flip the Lid" did not receive an appropriate response.

> We had to think of, oh, they're on there playing games or they're doing this or they're doing that, and I'd take their device off them. You've no longer got a device. And next minute we'd go, if the student's drawing in the back of the [exercise] book … do you take their exercise book from them? It's the same thing - you're taking their book, you're taking their learning from them ... the staff were coming to us, going, "Well, they're not doing the right thing. They're not flipping their lid. What are you going to do about it?" (Matthew, SJW1 0:23:38)

Thus, with an appreciation that device misuse does occur, the leadership team at St John's Wood created a protocol for the chain of events that would be put into effect following a transgression:

> And so [there are] a series of steps teachers would take … kid caught doing the wrong thing on their device, first level might be, like a detention ... Continue, that's when co-ordinators get involved, parents get involved. The only time that a device is confiscated straight away, if it's something that's a child protection issue,

or anything is slightly inappropriate, or if there's any suspicion of child protection issues. And then it's straight to [the principal]. (Mark, SJW1 0:23:38)

Staff at St John's Wood held the philosophical position that students needed the devices for learning, but also recognised that discipline was fundamental both to student development and the effective running of the school. It was therefore incumbent upon the leadership team to integrate device-specific behaviour management protocols with procedures that were consistent with disciplinary measures that would have applied to transgressions in a pre-mobile-learning era. The procedures that resulted from consultation with their pastoral care team and subject co-ordinators were considered to be compatible with both teachers' and students' existing conceptions of behavioural norms; and so, being well within the Teacher-as-Learner ZPDs, temporal restrictions became both socially accepted and well understood by all parties (Figure 5.17).

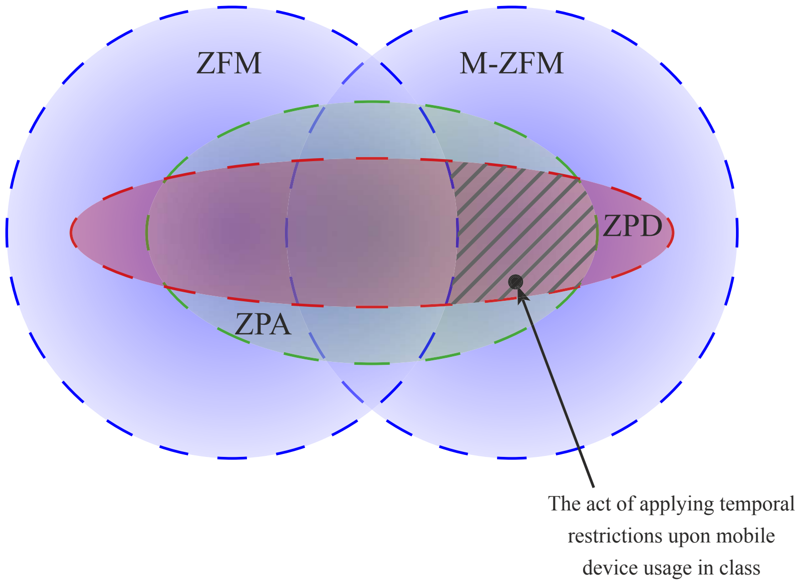


Figure 5.17. Positioning of the application of temporal restrictions, for the Teacher-as-Learner.

5.2.5.2. Device Locking

A more circumspect and permanent solution for narrowing the M-ZFM is made possible through device administrator privileges. Following experience with device usage issues for younger students, Moorgate Secondary College instituted a management system whereby the teachers would maintain full control over the iPads owned by every student in Year 7:

> The way we set this year up, we had control of their iPads for the first term, and they didn't have access to the App Store … Just being a bit more proactive. We didn't want them to have a free run on their iPad. We wanted to actually let them know that it was a learning tool. So they only had, sort of, educational apps on there. We push the apps out to them. So they could only use what we said. (Margaret, MSC2 0:02:48)

This narrowing of the device's ZFM changed the characteristics of the teaching and learning dynamic, so that the M-ZFM became roughly aligned with the ZPA (Figure 5.18).

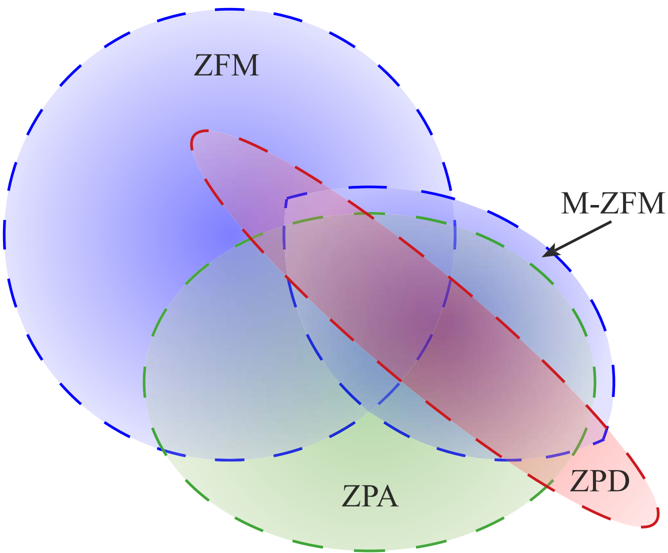


Figure 5.18. Zone configuration when device management is under teacher control.

While the restriction is necessarily imperfect - as an example, a student might access their English homework during Maths class - the control this method offered was considered by both teachers and parents to be an advantage.

An interesting side-effect of this method was that the M-ZFM would be maintained irrespective of whether the student was in class or not. This differed from Bring-Your-Own-Device arrangements for which the mobile technology would only need to conform to a much looser specification. Moorgate's choice to require all students to purchase identical devices allowed the school to manage all of the devices in an efficient and scalable manner; if the devices were of different makes and models, then it would not have been practical for the school to maintain this level of control. Indeed, with access restrictions becoming increasingly unenforceable due to consumers having access to personal mobile data (Deloitte Touche Tohmatsu, 2016), it is unlikely that schools will be able to continue to police whatever it is that students actually do, on devices that the students themselves own and administer. Thus, while schools will need to maintain proxy services to ensure that the school's WiFi network is not being abused, there is unlikely to be any real restriction on what students might access - whether on school grounds or otherwise.

5.2.6. Streaming and the Zone of Free Movement

In considering the implications of mobile learning for assessment, and vice versa, it may at this point be useful to recap the reasons for the relevance of the preceding discussion regarding students' behavioural maturity. To this end, we shall explicitly associate mobile learning with the Zone of Free Movement, as it is evident that the introduction of student-centred mobile device usage has a significant impact upon each student's ZFM. Similarly, we shall consider assessment as having a close relationship with streaming, as - at least in the case study schools - streaming practices were invariably informed by an assessment of some kind. The issue at present is therefore to examine the relationship between streaming and the ZFM, where the ZFM may vary according to the inclusion or exclusion of the M-ZFM.

Despite the second-tier nature of these relationships, this particular connection between mobile learning and assessment appears to be surprisingly robust. If we remove the intermediate steps, what remains is a link that is apparently causal: assessment results directly influence the teacher's implementation and management of the students' mobile learning. This was true even of cases such as Moorgate Secondary College, where the initial assessment was conducted, not through an assessment task, but rather through teachers' perceptions of what might be expected of Year 7 students. The teachers had, essentially, "assessed" the students even before they had met them.

Thus, the introduction of student-centred mobile device usage assumes that the students in the class exhibit a certain level of behavioural maturity. Irrespective of whether or not such assumptions are well-founded, the onus remains on the teacher to maintain order and emphasise learning despite the presence of these devices, with their inherent ability to dramatically increase each student's Zone of Free Movement.

At this juncture, it may be salient to consider the analogy that is often made between mobile device misuse and pre-mobile-device forms of off-task behaviour. To reiterate a point made earlier, the leadership team at St John's Wood Catholic College discussed the need to regulate teachers' reactions to device misuse (see Section 5.2.5.1); but while the analogy with "drawing in the back of the [exercise] book" may be reasonable for the purposes of demonstrating the logistical implications of confiscating the student's mobile device, it tends to gloss over the question of the student's increased ZFM. As numerous studies on gaming and social media addiction attest (e.g. Ryan et al., 2014; Cash et al., 2012), mobile devices offer scope for entertainment and behaviours that are far more diverse and sophisticated than doodling in the back of an exercise book. Ragan et al. (2014) particularly discussed the frequency with which students accessed social media, games and web browsing, and, as described by Shek et al. (2009), attributes of internet use also include such potentially desirable affordances as anonymity, greater control over one's self-presentation, opportunities to fulfil the need for belongingness, and escape from emotional difficulties and personal hardship. It would be reasonable to expect that, for adolescent students, there is the potential for internet-enabled off-task behaviour to present as a more attractive option than school mathematics.

Unregulated mobile device usage essentially offers students more, and potentially more appealing, opportunities to exit the Zone of Promoted Action being maintained by the teacher. Of these expeditions, there are certainly some which position the student as a "seamless learner" who can, "mediated by technology … explore, identify, and seize boundless latent opportunities … rather than always being inhibited by externally defined learning goals and resources" (Milrad et al., 2013). One example of such behaviour was observed at Farringdon High School, where a Year 11 Extension 1 student ignored the anti-differentiation exercises that had been set for the class, preferring instead to play with a graphing application. Classmates watched as he experimented with creating graphs that would take on a particular appearance, and offered suggestions of graphs that he might try to produce. It could be seen that this student's exploration of the effects of changing the parameters of the graphs was arguably beneficial for his mathematical development; and through his explanations of his findings to his neighbours, it was evident that his understanding of the characteristics of polynomials was becoming increasingly sophisticated.

While the mobile device undoubtedly allowed this student to explore facets of mathematics that were not being promoted within the classroom setting, it is evident that there is likewise potential for students' technology usage to be educationally bankrupt. With student-centred mobile technology being very nearly a constant presence in their classrooms, teachers at Moorgate Secondary College readily admitted to the potential for the technology to be a source of distraction. As explained by the teacher of a Year 9 science class,

> You would have [seen] - Max, once he'd finished his work this morning, went to YouTube ... What's on YouTube - well, it's the right stuff today, but, it's very easy to go to something else on there. It's an ongoing issue, but the way you set up your rooms … if you're hiding in the corner, it's generally a dead giveaway that you're hiding something, so you're probably not on task. (Simon, MSC5 0:08:30)

It was therefore interesting to note that Moorgate Secondary College chose to phase out iPad restrictions during Year 7 and 8, and indeed upheld the idea that self-restraint was a quality that should be deliberately instilled into students:

> Year 7 and Year 8, they probably do a lot more restricting of iPads, so access to certain sites or games or, you know, really getting there and putting restrictions on. It's something I do in Year 9, I say, "Look, I don't want to do that. I can, but I'd much prefer you to have access to everything, and be responsible with how you use it. Because whether it's next year or the year after or your work life, those restrictions won't be there, and if you can't focus on what you need to do because you're distracted by something else. I want you to try and learn that now." (Simon, MSC5 0:07:52)

The implementation of this kind of learning - that is, learning how to use mobile technology usefully and responsibly - necessitates the presence of a complete and uncensored M-ZFM. Thus, in realising this idea of the skills that students actually needed to acquire, Moorgate would start students' learning by offering few opportunities to deviate from the ZPA. Then, the M-ZFM would gradually be expanded, while signals would be maintained regarding the impropriety of spending class time in the newly accessible areas (Figure 5.19).

Moorgate's approach to the issue of streaming and its relationship to the M-ZFM essentially offered the somewhat radical proposition that all students should, and can, be taught to behave responsibly while using mobile technology in class. It should here be noted that Moorgate's current method of implementation was relatively new, being introduced for the Year 7 cohort in 2016, after four years' experience with other methods of managing device usage. Indeed, this practice effectively demonstrated the completion of some learning on the part of the teaching staff, with classroom management and device management methods being mastered by Teachers-as-Learners.

The relatively slow acculturation that occurs through the process of gradual ZFM expansion is characteristic of many of the choices that were made at Moorgate Secondary College. Instead of quick implementation and the expectation of rapid results, Moorgate had spent four years slowly moulding its approach to mobile learning, and considered pedagogical modifications as a long-term initiative:

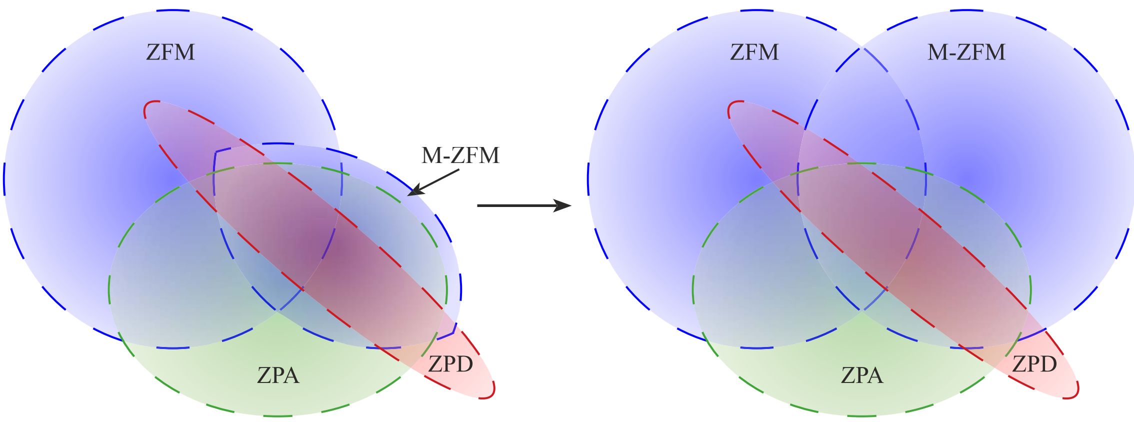


Figure 5.19. Teaching that is implemented solely through the changing of zone configuration.

> Probably the thing we'd like to shift to a little bit more in the future is the collaborative aspect of online connections. So, not only within our own school, so the kids being able to peer teach, or share their own learning, between each other, but also being able to connect to the outside world a little bit more. Because I think in the first four years we've just been focused on getting things right here. I think it's probably a good point for us to move forward next. (Ellen, MSC6 0:03:11)

However, the experience Moorgate has gained regarding methods of device management is not, using currently available technology, practically applicable for many school situations (Figure 5.20). In particular, at the current point in time, Moorgate's approach is unlikely to be realistically achievable for schools where the devices are not uniform. Even if students are all asked to procure devices to a particular specification, the school must be able to request sole administrator privileges on every student's device. Additionally, school staff must be confident that they are capable of managing all of the student devices efficiently and scalably, and that they have the technical expertise required to gradually roll out access privileges, troubleshoot security breaches and maintain the requisite level of control.

Of the case study schools, only Moorgate and St John's Wood Catholic College had mandated a particular variety of mobile device for school use. Bermondsey College and Chesham House "strongly suggest" but do not demand particular device specifications, while Elm Park, Farringdon and Osterley High School offer little guidance beyond the requirement that the device be able to connect to the school WiFi network. It is therefore the case that, with an approach that suggests considerable forethought, or perhaps some serendipity, regarding device management issues, Moorgate and St John's Wood were the only schools in this study that might reasonably be able to implement a slow and controlled rollout of device access privileges.

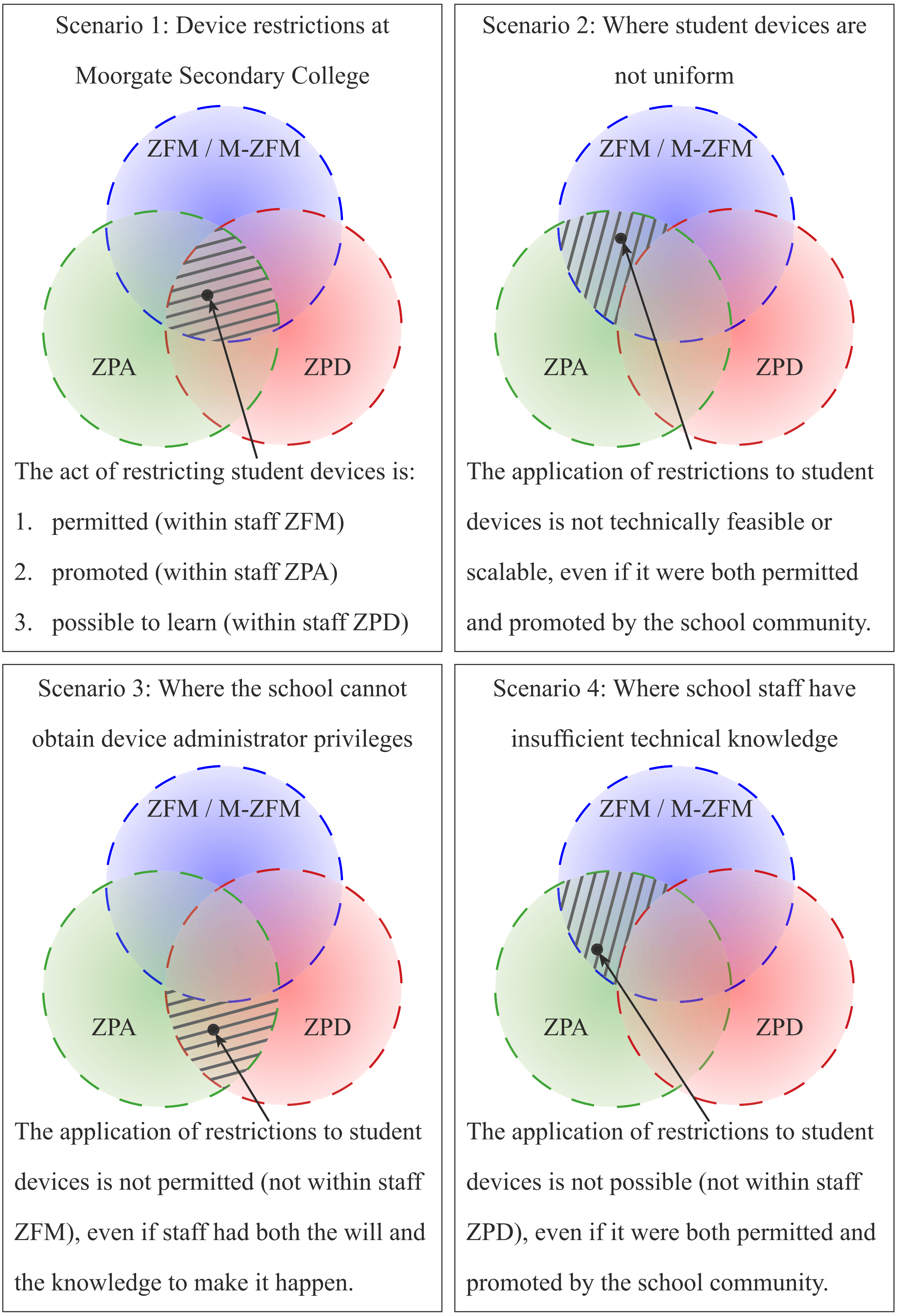


Figure 5.20. Teacher-as-Learner positioning of the application of device restrictions.

5.3. The Influence of the M-ZFM upon Mathematics Assessment

From 2019, modifications are slated for the assessment schedule for advanced mathematics courses in the NSW Higher School Certificate. Perhaps the most contentious of these modifications has been the mandating of two assessment tasks, one in Year 11 and one in Year 12, that are either assignments or investigations - that is, neither examinations nor tests. As outlined by NESA (2017a and 2017b), the assessment program must adhere to the following requirements:

> Year 11: Three assessment tasks [of which] one task must be an assignment or investigation-style with a weighting of 20 - 30%.
>
> Year 12: A maximum of four assessment tasks [of which] one task must be an assignment or investigation-style with a weighting of 15 - 30%.

With two of the seven case study schools (Elm Park High School and Farringdon High School) choosing, to date, to conduct summative assessment in mathematics exclusively through tests and examinations, the introduction of a compulsory assignment-based assessment component for the senior students requires a considered rethink of their entire approach to mathematics assessment - and, to some extent, mathematics pedagogy. As discussed by Mislevy (2013),

> assessments do not simply measure existing qualities in students, and they don't even just shape the development of those qualities. Rather, in a degree that is arguable but an effect that is not, they cause those qualities to exist, and peoples' lives and practices to adapt to them. (p. 9)

The valuing of project work in such a high-stakes assessment necessarily influences the nature of the emphasis in mathematics teaching and learning. To illustrate this, we shall employ the Zone Theory model to visually represent the change.

5.3.1. Zone Theory Representations

Figure 5.21 shows the application of Valsiner's Zone Theory to the change in assessment regime for a Teacher-as-Learner. In this circumstance, the environmental changes are being managed by NESA.

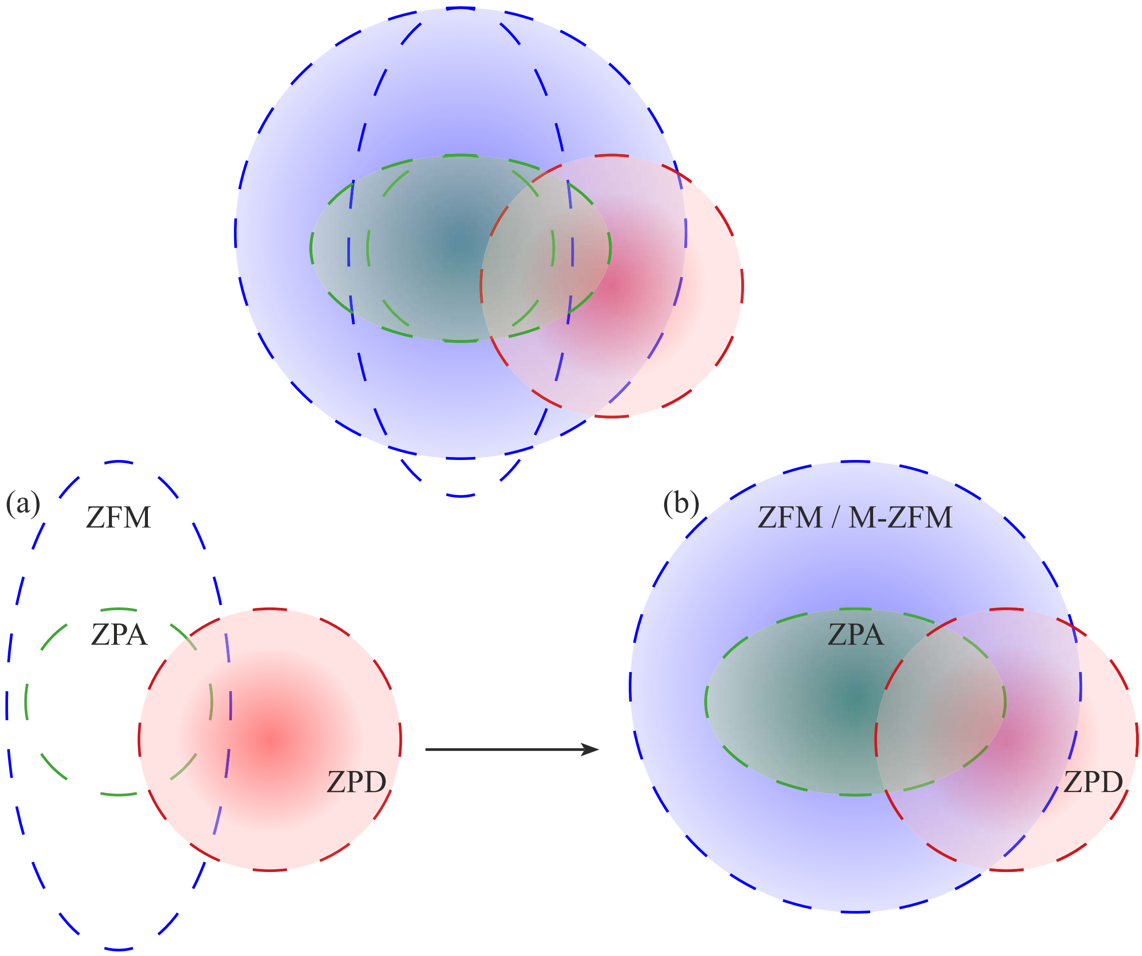


Figure 5.21. Change in pedagogy due to change in assessment, for Teacher-as-Learner. From (a) before 2019 syllabus for advanced mathematics to (b) following directives regarding mandatory assessment activities.

While the "before" and "after" diagrams are topologically identical, they are presented in this manner to allow comparison by superimposition. Note that the oversimplification of the diagram should not adversely affect its ability to illustrate the cases in this circumstance.

In this scenario, the Teacher-as-Learner's ZPA must expand to encompass the teaching and learning that the new assessment schedule is intended to encourage. It should be noted that the ZPA is only being augmented, not reduced. With students being required to submit to an additional assessment method, the expectation is that teachers will increase their pedagogical repertoire to suit. This does not, however, mean that teachers must not structure learning activities around assessment by examination; such activities remain in the ZPA (Figure 5.22).

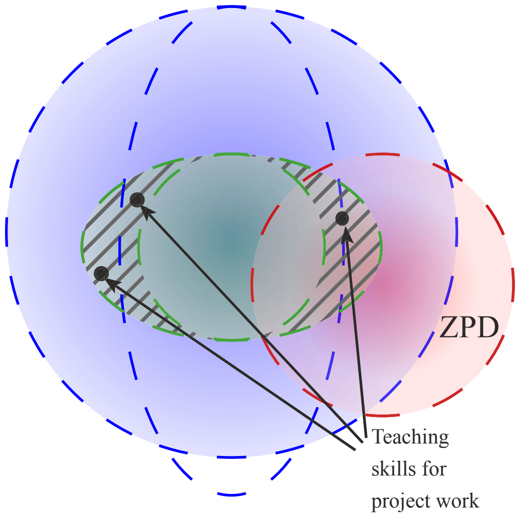


Figure 5.22. Positioning the introduction of pedagogies aimed towards assessment by project work: Augmentation of the Zone of Promoted Action.

These modifications to the ZPA are limited in their effect on the ZFM. Changes in this regard exist solely for the purposes of expanding the ZPA of teachers whose prevailing school cultures had previously discouraged or eschewed project work in mathematics. Under such circumstances, a ZFM expansion

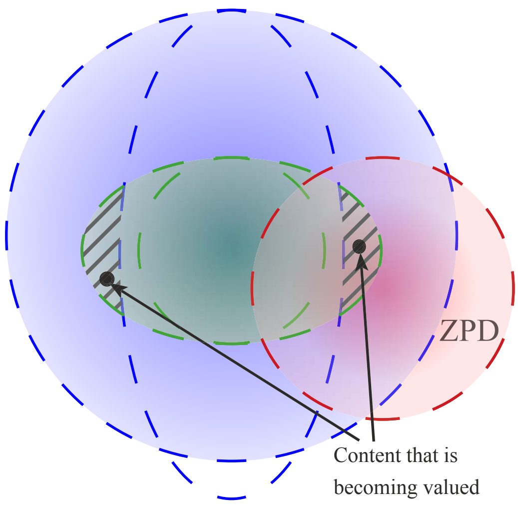


Figure 5.23. Positioning pedagogies that were previously disallowed, but are now required for the new assessment regime.

is required to acknowledge the necessity of engaging with project-based pedagogies (Figure 5.23).

Throughout all of these zone changes, the ZPD is, of course, unaffected. Since the ZPD is internal to the teacher, it is not subject to manipulation by the changing of departmental guidelines; rather, it is only modified after the teacher (as learner) engages in an act of learning.

It can be seen that these diagrammatic representations offer only one possible interpretation of the effect of the change in assessment regime. To be explicit, the position of the action "to promote skills and strategies related to project work" is ambiguous, and depends upon the school's understanding of what such an assessment would entail. If we consider the assessment requirements at face value, in particular the directive that, for Year 12 students' school-based assessment,

> one task must be an assignment or investigation-style with a weighting of 15-30% (NESA, 2017a and 2017b),

it is evident that the guidelines mandate engagement with project-based assessment. However, this injunction differs fundamentally from communications regarding centrally managed assessment, because it does not specify the nature of the school's commitment. Thus, while departmental directives may imply such an obligation, the choice regarding how to engage is still dependent upon the school. To illustrate this, we need to augment the zone diagram so that it includes two ZPAs, maintained by two stakeholders: the department (NESA), and the school community (Figure 5.24).

The difference here may be illustrated through reference to some notorious incidents in HSC-level teaching and assessment. Singhal (2017) describes an error made by one school, which taught the General 1 syllabus to its HSC General 2 cohort. While the

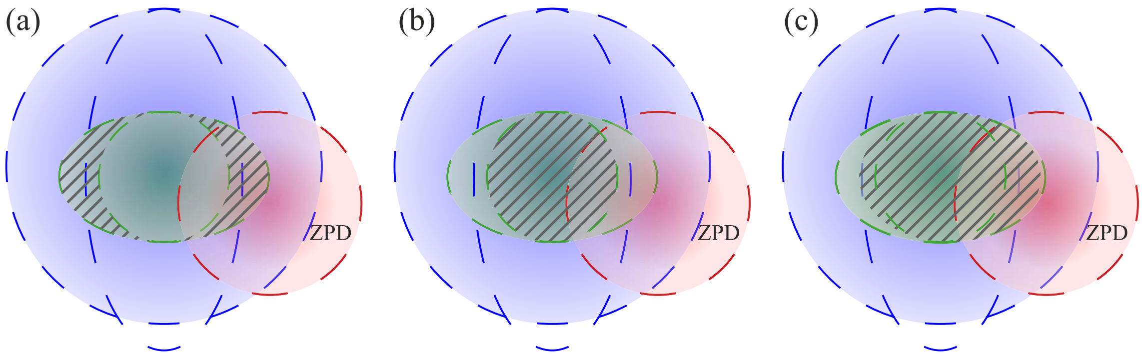


Figure 5.24. Positioning the ZPA for a school's approach to mathematics pedagogy.

(a) ZPA for pedagogies that support project-based assessment, as described by NESA

(b) ZPA for a school exhibiting indifference and/or disregard

(c) ZPA for a school that chooses to engage.

school in this case was publicly reprimanded and obliged to remediate the oversight, it is unlikely that a mishandled school-based internal assessment would have generated a similar level of fuss. In the case of the school described by Singhal, it was probable that the controversy owed much to the centrally managed and thus non-negotiable nature of the impending assessment.

5.3.2. Project-Based Assessment and Mobile Learning

While the change in HSC assessment requirements is not explicitly linked to mobile learning, it would appear that the new assessment regime is positioned to encourage recognition of the importance of mathematics as a social exercise. With suggestions for appropriate tasks including

- an investigative project or assignment involving presentation of work in class
- an independently chosen project or investigation

- scaffolded learning tasks culminating in an open-ended or modelling style problem
- a guided investigation or research task involving collection of data and analysis

  (NESA, 2017a and 2017b)

it appears that the assessment task is intended to promote applications of mathematics in real-world contexts; and while it is not prescriptive regarding the use of technology, it is evident that the nature of the task supports the assessment of mobile learning in mathematics. That is, the task offers scope for the assessment of mathematical skills that can be demonstrated with the aid of technology. As noted by Leigh-Lancaster (2010), such a task would be a necessary component for the implementation of curricular expectations in technology-enabled mathematics:

> If curriculum is to say what students should, as a consequence of their learning, know and be able to do (concepts, skills, processes and the like) and assessment is the means by which judgments are made about progress and achievement, then a curriculum that sets expectations for the active use of technology as an enabling tool for working mathematically requires congruent expectations and practices for assessment.

Thus, while the regime does not specifically note the applicability of mobile device usage to the production of the assessment artifact, the mandating of such an assessment signals a high-level awareness that schools now require an assessment method that is able to value skills associated with technology use. Pea's (1987) description of the purpose of cognitive technologies foreshadowed the mathematical abilities that will be valued when technology can be used to replace "the drudgery of remembering and practicing cumbersome algorithms"; and since Weiser's (1991) characterisation of ubiquitous computing, the ability of personal technology to support distributed cognition has gradually become a reality. Following Pea and Maldonado's (2006) description of computers

> embedded in everyday life activities to the point of "invisibility", so that we unconsciously and effortlessly harness their digital abilities as effort-saving strategies for achieving the benefits of "distributed intelligence" ,

we now have "generalised mobile devices with integrated functions, cognitive tools for doing things, like mapping concepts, running simulations, gathering data and structuring discussions" (Laru & Järvelä, 2015, p. 474). In this distributed cognitive system, "routine cognitive tasks are performed by tools (technological artefacts) and more complex communications and tasks are the core intellectual capabilities of people" (Laru & Järvelä, 2015, p. 473).

In effect, while mobile device usage is not specifically mentioned in the new assessment regime, it certainly appears that the directive aims to encourage the development of students' distributed cognitive capabilities. With the increasing ubiquity of mobile devices and their attendant support for applications of distributed intelligence, it would be reasonable to expect that a majority of the implementations of this assessment would include student-centred mobile device usage. It is therefore apparent that, in instigating the change in assessment methodology, there has been high level consideration given to student-centred mobile device usage; and, given that the outcome has been to execute this change, there is also evidence of high level support.

Thus we have a circumstance where a high-stakes assessment task apparently permits, and can be perceived to encourage, the employment of mobile pedagogies. Despite the lack of an explicit acknowledgement of the relationship, the current state of mathematics education and technological affordance implies a bidirectional association between this assessment task and mobile learning. In effect, the use of mobile technology in supporting mathematical thinking cannot be adequately assessed without offering students access to mobile devices whilst undergoing the assessment; and conversely, there are clear expectations that implementations of this assessment task will see students using their mobile devices for the purposes of producing a mathematical outcome.

With the introduction of this assessment regime being slated for late 2019, there is as yet no data upon which to draw for the purposes of determining its effects. However, it would be reasonable to assume that implementations will not significantly differ from mathematical investigations and assignments that have been used in the past. We shall therefore turn to past experience in an attempt to gain some insight into potential outcomes of the proposed assessment methodology.

5.3.3. Skill Development

It is evident that the rationale behind modifying a prevailing high-stakes assessment regime must include compelling arguments regarding the benefits of the new methodology. In the present case, it is asserted that the purpose of the change is to:

- rebalance the emphasis on assessment to allow more time for teaching and learning
- maintain rigorous standards
- provide opportunities to assess students' depth of knowledge and their conceptual, analytical and problem-solving skills.

  (NESA, 2017c)

With increased significance attached to students' "conceptual, analytical and problem-solving skills", it may be inferred that the newly introduced mandatory project work component is intended to offer a means of promoting and valuing this kind of skill development. As an aside, it is interesting to note that there are indications of a kind of pragmatism in the implementation of this change in emphasis. Rather than merely adding "conceptual, analytical and problem-solving skills" as an aim in the syllabus, having them inserted into the assessment program virtually guarantees that consideration will be given to their significance in the acquisition of mathematical competence. By including it in the assessment, it becomes far more difficult to ignore the overall intention to engage all students in the development of such proficiencies.

5.3.3.1. Comparisons with the International Baccalaureate (IB)

The examples of assignments and investigation-style tasks offered in the syllabus documents bear some similarity to the Mathematical Exploration task that has been an integral component of the IB mathematics assessment since 2014 (IBO, n.d.c and n.d.d.). With Mathematics Advanced being roughly comparable to the International Baccalaureate's Mathematics SL, and Mathematics Extension 1 and 2 comparable to Mathematics HL, it would be expected that the reasons given for the new assessment regime in NSW would bear some similarity to the IB's rationale for the exploration task:

> The internally assessed component, the exploration, offers students the opportunity for developing independence in their mathematical learning. Students are encouraged to take a considered approach to various mathematical activities and to explore different mathematical ideas. The exploration also allows students to work without the time constraints of a written examination and to develop the skills they need for communicating mathematical ideas. (IBO, n.d.e)

As a school that offers the International Baccalaureate as an alternative to the HSC, it is notable that Bermondsey College implements the IB Mathematical Exploration with a strong emphasis on technology use. As discussed by mathematics teacher Philip,

> they're allowed to use anything to do that, right. So you know your question about, can they go and talk to people, can they use the internet - Yep. Yep. And they're encouraged to. They're encouraged to use technology. And it's got to be a word processed document (BC1 0:27:17)

even though the International Baccalaureate's own guidelines permit handwritten work, and, like the NESA documents, do not deliberately prescribe the use of technology in any form (IBO, n.d.f).

Philip considers the inclusion of the Mathematical Exploration in the IB assessment schedule as being of particular benefit for the students' development, noting that it assists with more than just their mathematical understanding:

> I think it's a brilliant idea. A really good way to actually develop skills that they need to develop … But that's, you know, Year 12. It's just a year before they're about to start university … And it builds skills that you need when you finish school and go into university. (BC1 0:25:31)

He contrasts this with the learning that occurs for mathematics that is assessed through examination.

> Being able to come up with a concept for a research project and write a report. That skill, in my opinion, is a lot more valuable than learning trig equations. Because, like trig equations, yeah I can remember how to do them, today … and then, a few years from now - yeah. Dunno. Forgotten all that crap!

> And it doesn't make any difference, that I don't know trig equations any more. I will never use them. Ever, in my life. Whereas the skills that's writing a report, I will use for the rest of my life. We all write reports, we all communicate, with some form which requires us to put our thoughts into a document … and give it to other people. (BC1 1:14:56)

However, it is obviously erroneous to expect that the provision of an opportunity to engage with project work is sufficient to create thoughtful, self-directed learners. The development of such research and report-writing skills also depends on other factors, including the student's own confidence in their ability to execute the task, and their motivation to achieve. Thus it was found that, while the IB task was conceptually sound, its pedagogical value would vary considerably, depending on the dedication and ability of the student:

> A lot of them just go, yeah I'll just go through the motions, and they sadly miss the opportunity. Well, probably not a lot of them, some of them do. The better students will really get into it. [It] makes me think, you know, it does boil back to motivated students wanting to learn, wanting to achieve. If you've got a student who's at the other end of the spectrum, that sort of task is terrible. It's just really hard. Because they don't know where to start. (BC1 0:32:31)

It is clear that, in Philip's opinion, the appropriateness of the IB task for students' development is highly dependent on the personal characteristics of the student. He describes an appropriate IB candidate as being a member of a small number of students who are able to cope with the rigours of the course:

> There's a lot of issues with doing it ... You've got to do three subjects at a higher level. Higher level mathematics is somewhere between 3 and 4 unit mathematics.

> So, that's hard, right. And then you've got to do 2 other subjects at a higher level. So if you're an OK student but you're not able to do Extension anything, in any courses, you can't do the IB. If you can't do a foreign language, can't do the IB … Then there's fail criteria, right. So if you don't get 12 marks out of your 3 high-level courses, you don't get a certificate. (BC1 1:39:50)

The fact that Bermondsey College, with its privileged student body, maintains a relatively small IB cohort, attests to the idea that the IB course is only suited to a minority of students; and it appears that, even within this select few, there were students for whom the Mathematical Exploration was particularly challenging. It is therefore unclear if the project-based assessment model is inclusive enough to allow all students to achieve, or if, indeed, students will have the skills to produce quality original project work in advanced mathematics.

5.3.3.2. Alternative Implementations of Project-Based Assessment

As a counter to the challenge and sophistication of the IB Mathematical Exploration, it would be well to consider the experience of schools that offer different interpretations of what project-based assessment in mathematics might look like. We shall begin with a trigonometry research task that comprised one of four assessment items for Year 9 students at Osterley High School (Figure 5.25).

With a considerable gulf between the assessment styles of the Osterley task and the IB Mathematical Exploration, questions must be raised regarding the nature of the skills that each task seeks to develop. To ground this discussion with an appreciation of the level at which the Osterley students were expected to be working, we shall here note that

You will need the 3 measurements:

- the length of the tree's shadow
- the length of your shadow
- your height

Divide the length of the tree's shadow by the length of your shadow. Then multiply the answer by your height. This will tell you how tall the tree is!

(Tree's Shadow / Your Shadow) x Your Height = Tree's Height

Questions: (4 marks)

a) What was the length of the tree's shadow?

b) What was the length of your shadow?

c) What was your measured height?

d) Calculate the tree's height, showing your working. Give your answer in metres to 2 decimal places.

Figure 5.25. Detail from Osterley High School's Year 9 assessment task. (Appendix A-11)

a comparable mechanism was discussed by Holly from Farringdon High School, while describing the levels of support offered in a Year 10 5.1 assessment:

> The way we're assessing them is, If the volume for a cylinder is V = blah blah blah. What's the volume of this guy. Right here! And I think that's really nice. What can you do? Show us what you can do. (FHS1 1:26:04)

It is evident that, through these closely guided assessment items, both Osterley and Farringdon were aiming to cater for students who need more support to achieve. The contrast between this, and the IB Mathematical Exploration, could hardly be more marked, with the one providing intensive scaffolding, and the other generally lacking any form of tangible guidance; and apparently neither being suitable for the assessment of an entire cohort of disparate learners.

With a highly diverse student population, Moorgate Secondary College overcame the challenge of creating assessment tasks that were suitable for all students by assuming that any one task could not fulfil this need. Instead, each assessment task is offered at four different levels of difficulty. Freedom to choose the level at which to perform contributes to the ingenuity of a design that offers a differentiated learning experience, whilst giving students opportunities to challenge themselves to achieve.

5.3.4. The Hidden Curriculum of Assessment Practice

The development of students' abilities to engage successfully with their mathematics assessment tasks is evidently a process that takes time. Indeed, all of the case study schools demonstrated that both teachers and students acquired a certain sophistication, borne from experience, regarding assessment expectations. Students at Elm Park were observed studying techniques for solving unusual problems in past HSC papers. In the lesson prior to an examination, students at Chesham House were observed specifically focusing on testing tips - investing time to write down all of their formulae at the start of the examination, unit conversions, and ways to avoid rounding errors when using a calculator. At Bermondsey College, before-school mathematics help sessions were fully subscribed in the lead-up to the examination period, and at St John's Wood Catholic College the leadership team noted how teaching changed prior to a test. It was apparent that, following exposure to their respective cultures, and the acquisition of the experiences and understandings that define it, students in all of the case study schools adapted, in large part, to the prevailing assessment conditions, developing nuanced internalisations of what was deemed unacceptable and what would be considered to be exemplary - in short, what it meant to perform in a manner consistent with the school's expectations.

With a particular emphasis on project-based assessment, it was interesting to note that, when it came to internalising a hidden assessment curriculum, the experience at Moorgate Secondary College appeared to be roughly consistent with that of other schools that employed more traditional assessment techniques. With a school culture that valued project-based assessment from Year 7, both teachers and students at Moorgate became familiarised with the assessment methodology, and like Bolton and Elmore's (2013) "controlling" structure, the students' understanding and acceptance of assessment expectations were established before they were required to become high-level participants. Thus, in a similar fashion to its gradual introduction of mobile learning, Moorgate offers students step-by-step guidance through the hidden curriculum of project-based assessment practice:

> But I think it happens in Year 7 and 8, so by the time they get to Year 9 … [they] know what the task card's expectations are, so, most of them are reasonably well trained before they get to Year 9. (Simon, MSC5 0:05:56)

The case of Moorgate Secondary College was particularly revealing for its explication of the subtleties of school culture. Like curricular education, there is a learning curve associated with the acquisition of competence in the "hidden curriculum" of school assessment practice; and until such norms are internalised, students must come to terms with what is considered to be acceptable (Konieczka, 2013) and the characteristics of curricular activity that are actually valued (Sambell & McDowell, 1998). It was only after having undergone the comparatively slow process of developing an ingrained disposition for these expectations through school life experiences - essentially the development of a form of habitus, becoming an embodiment of those school values that would be prerequisite for meaningful interaction within the school, as regards academic expectations - that Moorgate's senior students were assumed to be able to engage with project-based assessment in a relatively equitable manner.

Thus senior students at Moorgate Secondary College were, as a cohort, considered to be capable of successfully engaging with project work and demonstrating skills related to project management. Indeed, with an entire curriculum based around project-based assessment, Moorgate deliberately considered all of the students' developing skills in light of their transferability. The aim, in this case, was to emphasise competencies that were actually applicable for life after school. As described by a Mathematics/Science teacher,

> from my background as a scientist, if I didn't know a species name, if I didn't know an organism or what it was doing, I would have to go to scientific papers, do the research, figure it out, and then put it into context. That's the powerful thing of learning. Getting students to regurgitate stuff en masse is kind of pointless. So, the challenge is to design assessment tasks that can't be copied and pasted from the Internet, but they can use research and stuff to inform their answers and give justification in their own words, is I think the depth of understanding. (Malcolm, MSC3 0:24:14)

This perspective would contrast directly with schools that may be obliged to introduce mathematical project work for the first time in the students' senior years. Having not previously conducted mathematics assessment in this way, the introduction of such a methodology would necessarily be disruptive to established norms for demonstrating student achievement. It would therefore be reasonable to expect it to require time for the students - and, indeed, the teachers - to attain an appreciation of, and fluency in, the different ways of thinking that will inform how a new assessment method must be approached. Similarly, time is also required to consider issues that are likely to interfere with the successful implementation of a novel assessment methodology.

5.3.5. Concerns regarding Assessment Integrity

Difficulties with project-based assessment are not limited to students' abilities to interpret the assessment requirements. From the teachers' perspective, confounding factors must include the increased complexity of the assessment process. It obliges an appraisal of what can potentially happen when assessment mechanisms change, and an appreciation of the incentive structures that will influence both teacher and student behaviour.

Perhaps the most obvious issue with a project-based assessment regime is the potential for students to submit work that is not entirely their own; although issues such as these are, of course, not limited to project-based assessment. In one notable example, O'Neil (2016) describes the cheating that occurred in the city of Zhongxiang, where students were renowned for performing exceptionally well in the national standardised test. An investigation one year saw students surrendering transmitters disguised as pencil erasers, and the uncovering of communications equipment in a nearby hotel.

> The response to this crackdown on cheating was volcanic. Some two thousand stone-throwing protesters gathered in the street outside the school. They chanted, "We want fairness. There is no fairness if you don't let us cheat." ... Whether or not it was the case, they had the perception that others were cheating. So preventing the students in Zhongxiang from cheating *was* unfair. (Chapter 3, "Arms Race: Going to College", para. 49-50)

Despite, or perhaps because of, examples such as these, it is evident that integrity is more easily enforced when students sit an examination. Indeed, the prospect of introducing project-based assessment is akin to removing all external barriers to outside assistance. Assessment by assignment implies a level of trust. With students encouraged to seek inspiration from external sources, and permitted to work on their assessment items without constant oversight, it is necessarily unclear how much of the student's work is, in fact, original.

While assessment integrity has always been a concern for the grading of coursework, the issue has perhaps not been as prominent for mathematics, which tends to maintain a reliance on tests and examinations of unseen content for a large proportion, if not all, of its assessment. Indeed, as discussed by Bridges et al. (2002), there is a pragmatism in including formal examinations as part of the assessment schedule, irrespective of the subject matter:

> One problem that is encountered by assessors is uncertainty as to whether the submitted work is that of the student. When the majority of students in a cohort achieve high marks, how is this to be interpreted? Is this result a reflection of industry, commitment and academic achievement or is it an indication of other factors? The answer in some instances is that the tutor is not certain, but the inclusion of a formal examination as part of the assessment provides the tutor with evidence of the candidate's ability. (p. 46)

Despite its relative inability to value depth of understanding over the capacity to articulate knowledge in time-constrained conditions, the examination is valued for its ability to offer unquestionable evidence of student achievement. With skills associated with traditional mathematics being largely examinable, mandated project-based assessment effectively introduces, for the first time, the idea that there will be elements of uncertainty regarding whether or not a student's submission truly reflects their own achievement. It paves the way for doubt regarding the provenance of submitted work to become an issue whilst grading.

Anecdotal evidence of unauthorised external assistance was offered by Bermondsey College as the reason that the school no longer conducted project-based mathematics assessments for its junior students:

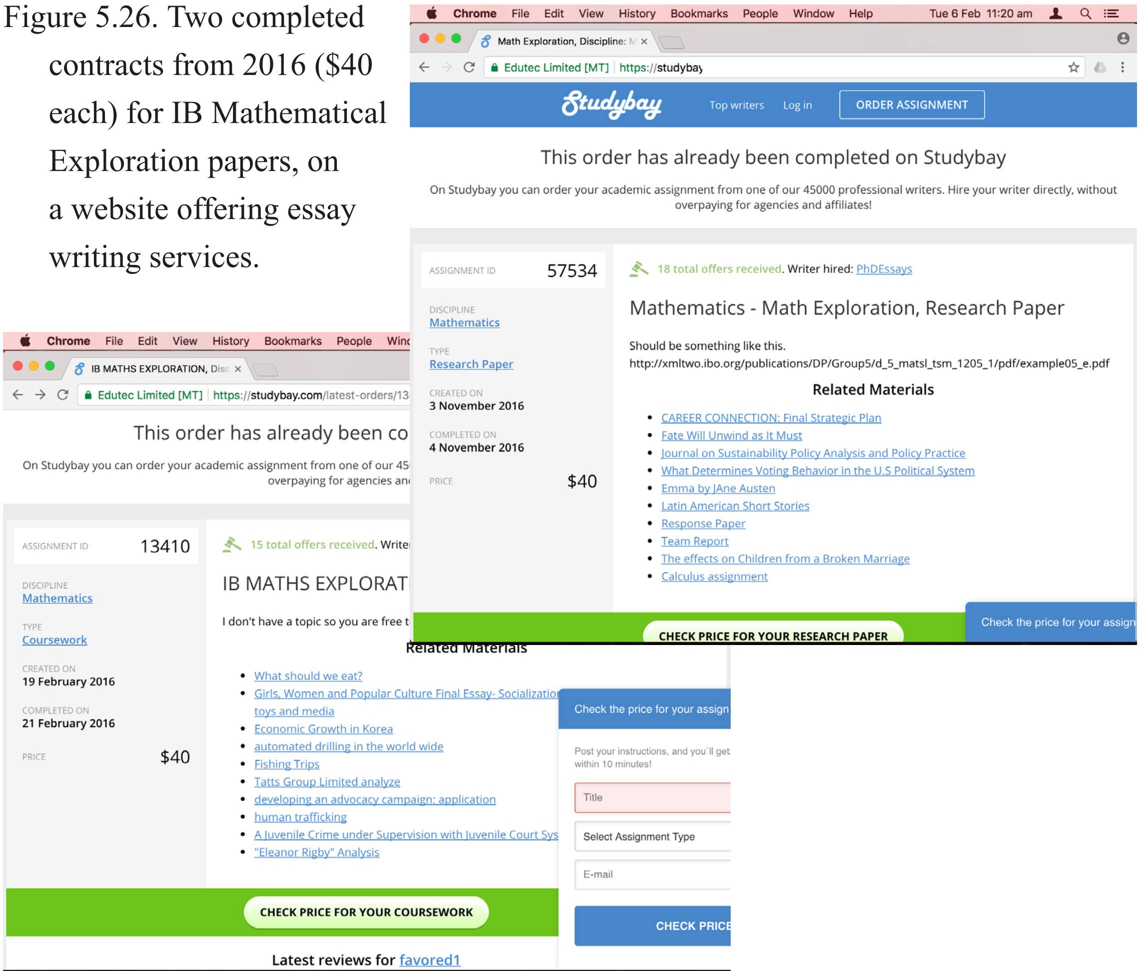
> In Year 7-10 it's just exams. Except we used to have sort of some assignment where they hand things in. And we found that typically that was either done exceptionally well, probably by someone else, or very poorly. So it was just - it didn't really actually give us a good indication about what the student actually knew. Does that make sense? Because all you'd get back was something the parent had done, or some tutor had done, or something else. (Philip, BC1 0:24:37)

The IB Mathematical Exploration handled this problem by requiring students to sign a declaration:

> They have to sign something saying that it's all their own work. Though, yeah it's serious if they're just getting someone else's work, and then they can get the guys their whole leaving certificate ... There have been, um, quite a number of instances where people actually paid for people to write these reports for them. (Philip, BC1 0:28:14)

Attempts to uncover the methods employed to obtain "someone else's work" for submission, led to the location of online vendors who would outsource the work for a fee (Figure 5.26). It is significant that this kind of academic misconduct is not detectable through current anti-plagiarism methods such as Turnitin, which can only match against work that has already been submitted or published elsewhere. Indeed, as discussed by Lancaster and Clarke (2016),

Figure 5.26. Two completed contracts from 2016 ($40 each) for IB Mathematical Exploration papers, on a website offering essay writing services.



> Since contract cheating is being considered to produce original work, this also means that a tutor looking to take a contract cheating case forward to an academic integrity panel will not usually have the benefit of being able to show where the student copied the work from. (p. 642)

The assessment of project work for students who value high marks has been particularly concerning for the academically selective high school Elm Park. According to head mathematics teacher Daniel,

> At this school, one thing that we do need to be careful of - because of the large candidature of the - and because we don't offer Stage 5.2, so we can't set a separate one for them, it's 120 sitting, doing the same task. It's how to minimise on the,

uh, academic misconduct. Plagiarising off the net, or off a friend, or otherwise. That's the big concern that the selective schools have. Because all of us will operate in a very similar way. That is, the 120 or 150, [do] exactly the same course. (EPHS1 0:30:19)

With a large cohort of academic high achievers who all study the most rigorous mathematics course, the problem of setting project work that would result in the production of unique and original artefacts is necessarily non-trivial. To illustrate one potential problem, mathematics assignments were obtained from two university students who were accused of collusion (Figure 5.27). According to the students, the assignments were independently produced and there was no collusion in the case. The reason that they gave for the answers being the same was that, as friends, they had helped each other to understand the coursework - and in so doing, had caused each other to perpetuate the same mathematical misconception.

With an intention to value mathematical work that permits the employment of distributed intelligence, project-based assessment offers a solution that, while appealing for its

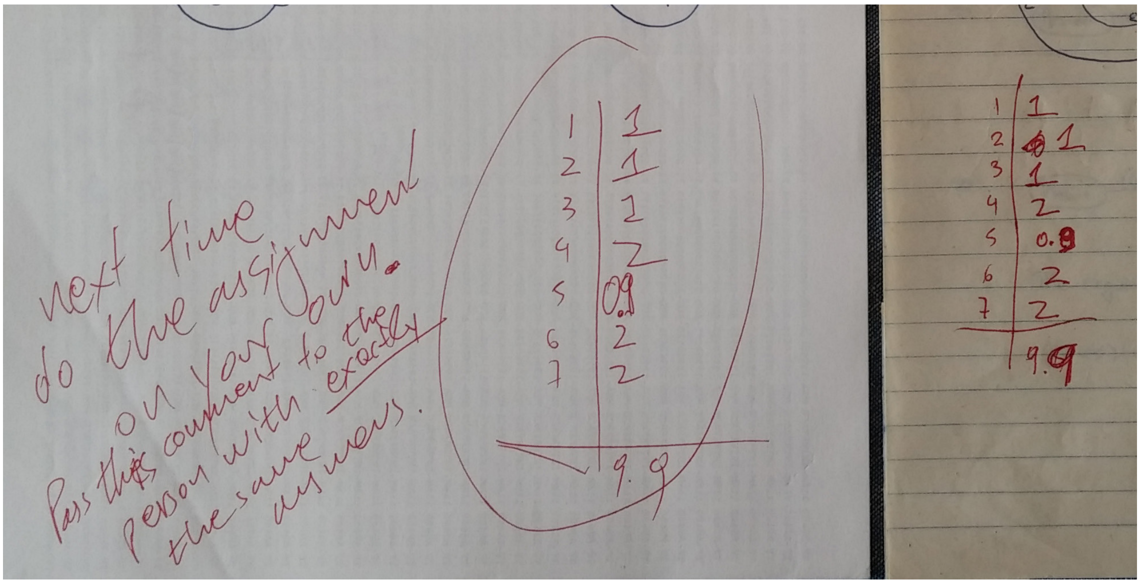


Figure 5.27. Comments on students' mathematics assignments.

pedagogical benefits, is also prone to being gamed. Issues with cheating are particularly problematic in this case because it is difficult for the teacher to definitively prove that cheating has actually occurred. Since mathematics is a discipline within which it is possible to have simple answers that are absolutely correct, it can be hard to distinguish between the student's ability to solve a problem, and the student's ability to choose the right friend from whom to copy.

5.3.6. Concerns regarding Time and Effort

Mathematics is, in a sense, peculiarly suited to assessment by examination. An examination offers the potential for a one-on-one interrogation of mathematical skills - a procedure that is both straightforward to administer, and relatively easy to grade. The production of correct responses infers a reasonable likelihood of mathematical understanding, while incorrect answers can be analysed for misconceptions and partial credit. As an assessment mechanism, the examination is efficient, scalable, and largely unarguable, producing objective "evidence" of student achievement.

Thus, with historical experience of straightforward and incontestable assessment practice, the inefficiencies associated with grading project-based assessments are cause for concern. It is apparent that the evaluation of mathematical project work differs fundamentally from the appraisal of a response on a mathematics examination paper - partly because the teacher must consider the possibility of academic misconduct, but also partly because the nature of the mathematics being assessed must change. Under examination conditions, assessments can include administrative measures that ensure the reliability of results from questions with short answers. However, such questions, while relatively easy to grade, are poorly suited to project-based assessment. There is too much potential for students to confer with each other to ascertain the correctness of each answer, and consequently the integrity of the assessment is liable to be called into question.

It is therefore the case that, for project-based assessment in mathematics to maintain some semblance of assessment integrity, the task must comprise questions for which students' responses are expected to be variable. To this end, one possible solution is offered by the International Baccalaureate's Mathematical Exploration task, which requires students to write a report on mathematics that they find personally relevant or interesting. The mathematics, in this case, must be of a difficulty level not less than what is included in the Year 11 curriculum.

Not only does this report require students to personally select the aspect of mathematics to discuss, but the grading rubric offers comparatively little credit for the mathematics in the report. That is, the only component that might reasonably be considered to be symbols-based and therefore amenable to objective grading practices, comprises a relatively small proportion of the final mark:

> Out of the 20 marks in the standard I-level report, the mathematical processes that you have to demonstrate in that assessment task is only 6 marks out of 20. That's how they value it. (Philip, BC1 1:16:20; see Section 4.4.4)

With considerable weight being given to skills other than those of comprehension and calculation, the Mathematical Exploration task makes it clear that what it values is a far broader interpretation of what is considered to be a mathematical skill. According to this premise, such skills include persuasion, clarity, and creativity, as well as (in the case of Bermondsey College) some sophistication in the use of technology for the purposes of producing the report. While this holistic approach is undoubtedly valuable for demonstrating the student's competencies, it fundamentally changes the process of grading the submission. In requiring a confluence of skills on the part of the student, it obliges the teacher to become expert in all of these skills, both in isolation and in combination; and it obliges the assessor to have the sophistication, not only to assess the extent to which all of these skills are exhibited, but also to assess the coherence of the report in its entirety.

The creation of such an assessment task therefore implies a considerable shift in what is expected of the mathematics teacher who supports its development, and who ultimately assesses the quality of the final product. To be explicit, the teacher is required to assess, in combination:

- the originality of the work,
- the clarity of its communication, and
- the correctness of the (Year 11+) mathematics.

As a grading exercise, this is decidedly different to the assessment of any other student submission that might be expected at a secondary school level. While it is currently standard for essays and reports in other subject areas to be graded for originality and clarity, or for mathematics to be graded for clarity and correctness, the combination of originality and mathematical correctness has the potential to be problematic. With a value judgement also being associated with clarity of communication, there are several considerations that can serve to complicate the act of assessment.

5.3.6.1. Time considerations

To illustrate one practical issue with the assessment of the IB Mathematical Exploration, Philip from Bermondsey College explained the commitment that was expected of the teacher. With eighteen students in his Standard Level (SL) class, Philip offered the following breakdown of the time that he spends grading this assessment:

In regard to the IB exploration papers. The process is:

- Review a draft
- Provide formal feedback to the student
- Meet with the student and discuss the feedback
- Review, mark and annotate the final submission,
- Scan, upload samples of my marking to the IB and enter results to the IB

Minimum of 4 hours per IA. So 18 students = 72 hours or two weeks' work.

(BC, personal communication)

Philip's exposition of the significant amounts of time and care required to assess project work was corroborated by head mathematics teacher Will at Farringdon High School. Although Farringdon has, to date, conducted mathematics assessments exclusively through tests and examinations, head teacher Will created a separate half-semester elective subject called "Exploring Mathematics" to enrich the mathematical offerings at his school for Stage 5 students. With no obligation to conform to particular syllabus outcomes, Exploring Mathematics offered opportunities for students to investigate mathematics of their own choosing, and some of the subsequent assessments took the form of project work.

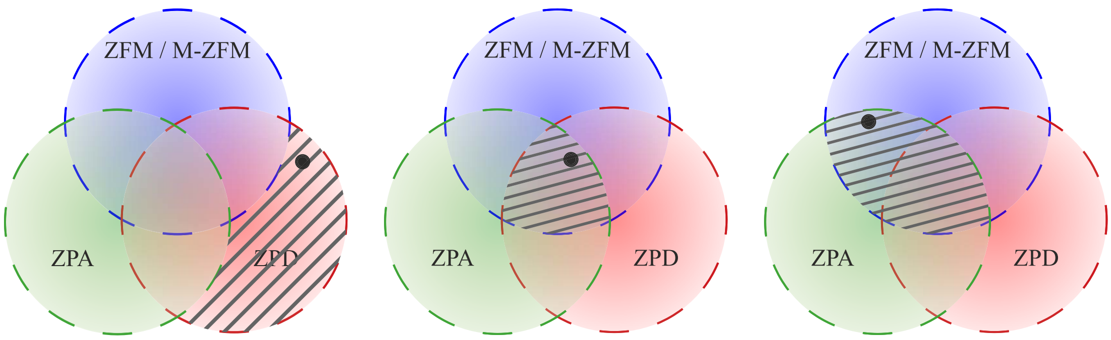
Students in the Exploring Mathematics course proceeded to produce some extraordinary work (see Figure 4.5) which inevitably led to questions regarding how it should be graded; and, as Will explained, the length of time required to mark one of these assignments "was considerable. No two ways about that." (FHS, personal communication)

5.3.6.2. Considerations of Effort

Issues regarding the amount of time required to grade mathematical project work necessarily pose the question of whether it is lengthy simply because the teachers have not yet internalised this particular skill. With a historical preference for grading work that has known correct answers, it may be argued that the teachers will become more efficient as they develop their own internal gauge regarding the quality of work that is expected (Figure 5.28).

The suddenness of the teachers' shift from minimal exposure to mathematical project work, to an expectation that they will possess enough expertise to judge student offerings, implies that the learning curve associated with developing this expertise is likely to be fairly steep. It may therefore be inferred that issues regarding time considerations may be attributed to teachers' lack of experience, and that the time investment will decrease as

Zone theory representations for the Teacher-as-Learner with respect to the act of assessing mathematical project work:



a) prior to the introduction of mathematical project work

b) following introduction of mathematical project work

c) after gaining experience in grading mathematical project work

Figure 5.28. Teacher-as-Learner positioning of assessment of mathematical project work.

the teachers become proficient. If this were the case, then the onerousness is likely to be temporary.

However, there is reason to suggest that this issue possesses layers of complexity that are not so easily resolved. In particular, the nature of the problem is unique simply because the subject area is mathematics. The grading of original project work in mathematics is unlike the grading of original project work in any other discipline because there is an implicit obligation to ensure that the mathematics not only appear competent, but is in fact correctly executed. As noted by Philip at Bermondsey College, the mathematics in the IB Mathematical Exploration papers must be drawn from the senior syllabuses - and thus the marker is obliged to check the correctness of what can potentially be highly esoteric mathematical thinking.

At this point, it is important to note that the grading of mathematics examinations circumvents this issue by allowing the assessor to define the mathematical construct that is to be solved. Therefore, despite maintaining a similar level of mathematical difficulty, the examination is easier to grade because the number of possible correct responses is finite. This differs fundamentally from the grading of original project work which encourages students to choose the mathematics for presentation. In discussions with a colleague in the School of Mathematical and Physical Sciences, analogies were drawn between this kind of grading, and the review of mathematical output in academia:

> One thing that occurs to me is that the picture of a teacher assessing non-routine, creative assignment work by students has a lot in common with a thesis examiner in mathematics, or a journal reviewer reading and trying to assess a new article written for a mathematical journal. These are mathematical activities, but certainly are different from standard marking of standard school or uni exams where the

problems are, as you say, set before hand by the teacher and have known solutions. (UTS, personal communication)

Indeed, an increase in the effort associated with assessment will inevitably occur, even if the tasks bear little resemblance to the IB Mathematical Exploration. The effort required to grade such mathematics is significantly increased even in situations where the assessor can set some parameters regarding what the project must investigate. Under such circumstances, the lack of a known correct numerical solution still obliges the assessor to verify each step of each student's working - a process that, for a mathematics examination, is essentially unnecessary for grading students who achieve a correct response, this being assumed to be a revealing symptom of proficiency.

5.3.7. Concerns regarding Fairness in Marking

For both Bermondsey College and Farringdon High School, the problem of assessing project work was further compounded by the teachers' innate sense of fair-mindedness, with what appeared to be a particular aversion to the inherent arbitrariness of subjective assessment. It was thus interesting to note the different perspectives that were brought to bear upon this issue.

At Farringdon High School, while Will did discuss the complexities surrounding the assessment of the project work, and the difficulty of doing so in a timely manner, it appeared that much of this struggle was internally imposed. That is, the requirement to grade fairly, which resulted in a comparatively lengthy assessment process, was due to the teacher holding himself to a particular standard of work. Since, as he explained, the course was his own invention:

> I was the god of this course. So I did not have to do the rubric with any degree of specificity. (FHS, personal communication)

the inference was that ultimately the assessment was based on his own subjective judgement, and the difficulties arose because he felt the need to justify the resulting grades. In subsequent years, Will delegated the teaching of the Exploring Mathematics course to some members of his staff, and in so doing observed that issues of fairness in grading practices became even more acute when there were multiple markers.

The problem of reconciling grades offered by multiple markers was further explicated by Philip at Bermondsey College:

> The way that the whole system works is, the teacher has to mark all of [the Mathematical Exploration papers] to this criteria, and submit the marks. And then they're all electronically uploaded as well, to the central IBO … [and] X percentage of them are moderated. So they're marked again, basically. So someone's going to receive your paper who could be sitting in who knows where. (BC2 0:09:00)

Philip subsequently discovered that his interpretation of the marking rubric did not fully align with the interpretation of another marker:

> Last year, I only had three students. And after I marked them, they all got moderated. They all got moderated down. And I don't know why. I still don't know why. I could justify, on the marking scheme, why I gave them that mark. Someone else has obviously got a different view. I don't know where the differences were. And we tried to find out, and we couldn't. (BC2 0:10:05)

Philip's confusion was particularly revealing for its insight into the difficulty of interpreting nuances in the language of the rubric:

> What's the difference between coherent and well-organised, and coherent, well-organised, concise and complete? It's a judgement call. (BC2 0:05:20)

and his frustration was compounded by the lack of transparency:

> So you go, well, that's a bit of a silly system then. Because next year, if they do it again, I'd mark them exactly the same again … It's still your discretion, you know. If you think that something's concise and complete, and someone else doesn't, who's to say? It's my view against theirs. (BC2 0:10:20)

Ultimately, Philip became reconciled with the grading issues by accepting that, when the marks were adjusted, it made very little difference to the student's final result.

> It's not like the Higher School Certificate where every single mark really really matters, because once the student gets above, in this course, 80%, they get the maximum mark. Right. They get 7. And that's it. It doesn't matter. So if they get 99%, versus 80%, they get exactly the same result. So it's like, well, are you really going to get really hung up over one or two marks? (BC2 0:11:15)

5.3.8. The Devaluation of Mathematical Accuracy

The foregoing discussion presupposes a perspective on mathematics assessment that has not, to date, been openly called into question: that is, an assumption of the supremacy of mathematical correctness. It is paradoxically revealing that, in their lack of deliberate specifications regarding the importance of accuracy, the NSW mathematics syllabus documents make it clear that accuracy is assumed to be of paramount importance. It is, essentially, so important that it need not be mentioned - as demonstrated by references to "estimation" in situations where accuracy is not expected.

It is therefore unsurprising that, in schools where students are, on the whole, academically ambitious, the teachers tend to demonstrate an appreciation of the importance of accuracy and correctness. This was particularly evident in discussions with Daniel at the academically selective school Elm Park, whose perspective regarding accuracy was singularly notable:

> I have to say, real life - accuracy is absolutely top notch. Estimation - Nah. (Laughs) Let's make it accurate. (EPHS 1:29:07)

While the other case study schools were more circumspect regarding the importance of accuracy, they all qualified their views by noting that an incorrect response still receives credit for correctness of working:

> The reason I've not [said it was most important], is because of this carry forward mistake concept. (Holly, FHS1 1:30:20)

Thus, with the HSC being the ultimate mathematics assessment for their students, the ability to demonstrate competence under examination conditions unquestionably plays a significant role in determining their students' future prospects; and while correct working is sufficient to gain a good pass grade, a focus on accuracy is essential for receiving the full complement of marks.

However, with indications that the grading of project work for mathematical correctness is non-trivial, it would be well to consider implementations of project-based assessment that are not as exacting as the IB Mathematical Exploration. As an example, a project-based assessment task was included for every year level at Osterley High School - for which the grading appeared to depend far more on students' literacy and presentation skills than on the accuracy of their calculations. With assessment tasks including the construction of a collage (Year 7), the determination of the height of a tree of the student's own choosing

(Year 9), and the completion of a workbook on driving (Year 11 General Preliminary Course Focus Study), the assignments appeared to consider mathematical accuracy to be peripheral to other indications of student understanding. For these assignments, the portion devoted to numerical, algebraic and geometric manipulations tended to value responses that were likely to be reasonable, rather than expecting responses that were incontrovertibly accurate. As an example, the Year 11 assessment task included questions such as the following:

> For the car you have just decided to buy, how much will it cost for you to register it, including stamp duty and transfer costs? (Appendix A-12)

Thus the choice to decrease the emphasis on mathematical accuracy in favour of demonstrations of mathematical sense-making can offer a practical solution that simultaneously justifies the aim of the assessment, while effectively circumventing the need to verify the accuracy of each student's calculations.

While this particular assessment model appeared to suit the needs of Osterley High School, the solution offered may perhaps be less appealing for schools with students who are more performance-driven. To be clear, the assessment model is dubious because it is a trivial matter for a savvy but unscrupulous student to submit work that is merely a subtle modification of the work being submitted by a peer. The ease with which cheating can occur significantly undermines the integrity of the assessment mechanism - an issue that is particularly problematic for distinguishing amongst a cohort of students who are all expected to excel, and whose assignments would all be expected to include a large complement of correct responses.

However, despite questions regarding the suitability of the Osterley assessment mechanism, there is an aspect of their assessment model that could potentially permeate methods of evaluating project work produced by higher-achieving students. In particular, it is interesting to note Osterley's choice to grade for literacy and presentation, with only a secondary focus on mathematical manipulations and minimal emphasis on mathematical initiative. With such a shift in focus, the assessment is inevitably skewed towards a subjective judgement, and the process of assessing such a project would become comparable to the process of assessing essays and reports in other learning areas.

In considering the applicability of this assessment model for academically ambitious students, it can be seen that there is, indeed, a precedent for a corresponding devaluation of mathematical correctness for high achievers. Without explicitly stating that accuracy is being depreciated, the IB Mathematical Exploration offers just 30% of the available project marks for the actual mathematics, giving the impression that the mathematics itself is of minor importance, and that the assessment is seeking the demonstration of more wide-ranging skills. The importance of mathematical correctness is then further diluted by the potential for the assessment mark to be moderated, which in Philip's case reduced his students' scores whilst having little effect on their final outcome; and this is followed by a further blurring of the result through a very coarse-grained approach to judgements of competence. The message here is subtle but comparatively clear: it may be a waste of time and effort to split hairs regarding something as insignificant as a minor mathematical inaccuracy.

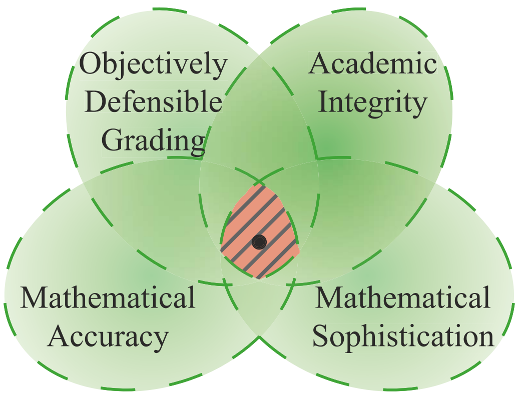
5.3.9. Zones of Promoted Action

In considering the introduction and execution of project-based assessment for secondary school mathematics, it is evident that there are multiple stakeholders, among whom there are likely to be differences regarding what constitutes a reasonable project-based assessment task. Of all of the interested parties, the only one for whom the ZPA is well defined is NESA, which provides a list of suggestions for what an assessment task might look like (NESA, 2017a and 2017b). In so doing, NESA offers some clarity regarding the kind of activity that it deems suitable. However, since the specification is worded in such a way that it does not meaningfully intrude upon the teacher's or the school's ZFM, the provision of this list carries little real weight. They are merely ideas, which the school is not obliged to adopt.

In comparison, ZPAs set by the school community are both nebulous and changeable. With confounding issues including the importance of mathematical accuracy and sophistication, an obligation to frustrate academic misconduct, and a need to maintain fairness in grading, it can be seen that the overlap between different ZPAs, informed by stakeholders with different priorities, will inevitably decrease. Common ground then becomes even more difficult to establish when the assessment task is removed from controlled conditions, as would have been offered by an examination.

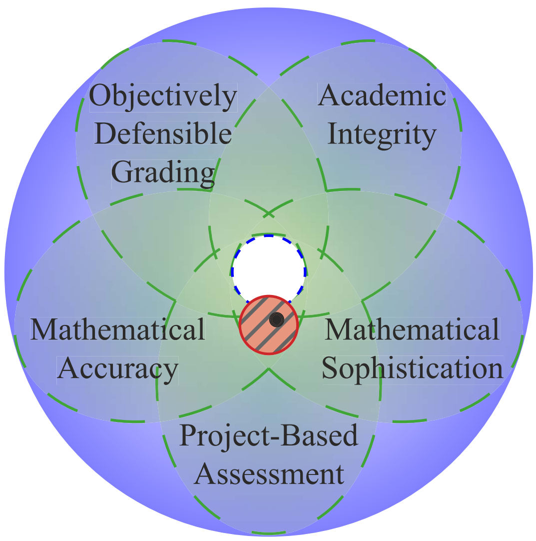
The ZPA complex must then also be considered in light of the school's ZFM. Despite the lack of such a specification, it is evident that an inhibitory ZFM must exist to illustrate the finite nature of teacher time. Thus it can be seen that an IZ, as theorised by Blanton et al. (2005) and adapted by Goos (2008) for the Teacher-as-Learner, is present in this scenario; and this IZ would include those Promoted Actions that are actually impossible due to time constraints.

Descriptions of this scenario must also draw upon Valsiner's caveat regarding "fuzzy or semipermeable boundaries" for phenomena that cannot be precisely described. While teacher time is obviously finite, it is impossible to quantify teacher effort. Considerations of time and effort in tandem are therefore obliged to adopt devices that offer less well-defined and more obscure representations.

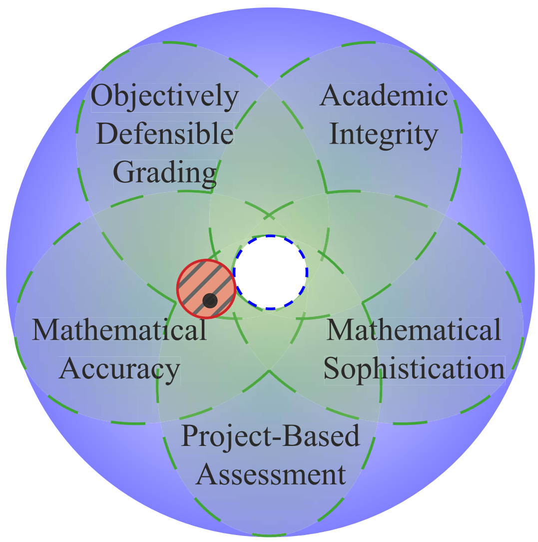


a) Assessment by Examination, representing a confluence of Zones of Promoted Action

b) ZFM representing the finite nature of teacher time and effort, from dark (achievable) to light (impracticable)



c) IB Mathematical Exploration task at Bermondsey College, and (to a lesser extent) Farringdon High School's Stage 5 Exploring Mathematics assessment



d) Project-based assessment tasks at Moorgate Secondary College and Osterley High School

Figure 5.29. Positioning mathematics assessment methods within Zones of Promoted Action.

Figure 5.29 offers an attempt to illustrate these zone configurations. In order to describe the ZFM for project-based assessment, we shall represent teachers' inability to spend infinite amounts of time grading by using darker shades of blue to indicate zones for which less time is required, gradually lightening to white to represent an infinite time commitment.

With experience from the case studies showing no single implementation that concurrently handled all of these competing demands, it is apparent that different schools chose to assign different measures of relative importance to each of the Promoted Actions, and manifested different levels of regard for the amount of time and effort expected of the teacher. In so doing, each situation had conceded the necessity of devaluing some characteristic of the (as yet non-existent) ideal project-based assessment task methodology. Such compromises suggest two things.

First, and perhaps most obviously, the presence of project-based assessment prior to its mandatory introduction indicates an appreciation that it is, in some way, an improvement over conducting assessments exclusively through examinations. It implies a recognition that examination-based assessments communicate a comparatively narrow sense of what a mathematical education is intended to achieve, and also conversely that they provide an incomplete picture of the mathematics that each student is capable of performing.

The second point is that, in creating project-based assessments that are apparently imperfect, there is evidence of an awareness at the school level that not all assessments must seek to satisfy the full complement of valued characteristics. An acceptance of the impracticality of inventing one assessment that suits all purposes effectively grants teachers the indulgence of creating assessment tasks that selectively promote characteristics considered by the school community to be of greater benefit to their students.

Thus it is apparent that, by mandating a system-wide change in high stakes mathematics assessment, NESA has forced all schools to make a choice. Given an assessment mechanism that cannot value everything, then what will the school choose to value? With an awareness that the students’ performances will only be compared with those of their peers, what mathematical competencies would the school particularly seek to endorse?

6. Conclusions

Mathematics in the primary schools has a good and narrow aim ... However, we have a higher aim. We wish to develop all the resources of the growing child. And the part that mathematics plays is mostly about thinking. Mathematics is a good school of thinking.

- Pólya*

* As quoted in Vinner (2013)

This concluding chapter will begin by considering the practical implications of attaching value to students' deep understanding in mathematics, and indeed to students' deep understanding of mobile technological affordances that could support mathematical thinking. Perspectives will follow regarding the use of existing assessment regimes to determine students' ability to benefit from engaging with "authentic" mathematical tasks that are enabled by mobile technologies.

The chapter will continue with a discussion of the impact of introducing mandatory high-stakes non-examination-based assessment in mathematics. With mobile devices generally proscribed for traditional examination-based assessments, the changes imply high-level support for all mathematics students to engage with assessment tasks that permit the use of mobile technologies; and thus consideration will be given to the meaning of such a change for the valuing of different kinds of mathematical learning.

A hierarchical structure will then be presented for students' mathematical learning and assessment, specifying a series of steps which, according to the findings from this study, must occur for the students to benefit from the affordances of "authentic" mobile learning. Consideration will also be given to issues surrounding the assessment of "pure" mathematical achievement, particularly with respect to the demonstration of such learning in a non-examination-based scenario, and the non-algorithmic nature of grading project work in pure mathematics.

Finally, future directions for research will be proposed, followed by perspectives regarding the purpose of a mathematical education.

6.1. Authentic and Instrumental Uses of Mobile Technology in Mathematics

While the interplay between mobile intensive pedagogies and mathematics assessment may be a topical issue, it is evident that the problem space bears striking similarities to Skemp's (1976) description of different kinds of mathematical understanding. Even if mobile technology can change what is valued in mathematical achievement, the essential difference between "relational" and "instrumental" understanding remains. As with Skemp, it is difficult to tell from a student's output - whether on paper or otherwise - whether or not the student's mathematical reasoning is valid, and their understanding conceptually sound. In the case of mobile learning, it appears to be just as difficult to tell if the student uses mobile technology in an authentic way to support mathematical thinking, or as a mechanism that can help to produce work simply for the purposes of passing an assessment.

Indeed, it may reasonably be argued that Skemp's perspectives regarding difficulty of assessment are not only relevant, but are in fact essentially insurmountable for mass assessment. In considering the characteristics of mathematics assessment tasks that could possibly lead to the determination of the nature of a student's understanding, it is evident that such an aim quickly becomes impractical for large-scale deployment. With a finite amount of time available to conduct and grade each assessment item, teachers must make compromises, and characteristics, such as the ability to solve authentic real-world mathematical problems, must inevitably be devalued.

Given that this is the case, then the question becomes, does it actually matter that inferences regarding students' mathematical achievements are made based on incomplete information? To date, this issue has generally been glossed over with a tacit acceptance that examinations, whilst necessarily imperfect, offer results that are reliable enough for the purposes of giving a rough estimate of students' attainments. For most objectives in secondary mathematics education, Skemp's "relational understanding" is assumed to correlate well enough with the demonstration of "instrumental understanding", and thus conducting a deliberate assessment of the student's "relational understanding" seems to be hardly worth the trouble.

With such a precedent, it is apparent that, just as the assessment of relational understanding is often relegated to an inference based on students' instrumental understanding, so there might be no real reason why we may not rely on proxies to infer sophistication in students' use of mobile technologies - provided, of course, that we acknowledge that that is what we are doing. With assessment mechanisms historically favouring the easily graded heuristic, there are indications that there is no systemic need to insist upon summative assessments that determine the student's ability to use mobile technology in a real and authentic way.

6.1.1. The Changing ZFM for Mathematics Assessment

NESA's initiative, in mandating non-examination based assessments in senior mathematics courses, compels schools to engage with assignment and investigation-style assessment tasks. It is therefore evident that there is high-level support for the idea that there should be assessments that allow the use of tools that are not generally permitted under examination conditions. Although this directive does not specifically promote the use of mobile technology, the lack of guidance suggests a familiarity with established parameters for project-based assessment, which would tend to include permission to use any tools that come to hand.

In essence, this initiative demonstrates an acknowledgement that distributed cognition forms an integral part of what is valued in mathematical thinking. It is a recognition that the ZFM for mathematics assessment must increase, and, as a departmental directive, it causes an immediate broadening of the set of valued mathematical skills, conferring weight and significance to the idea that students should be given the opportunity to demonstrate what they can do under working conditions that are more current and more authentic. In so doing, it implies an acceptance that students will choose the tools they deem most appropriate for supporting and enhancing their own mathematical experience.

6.1.2. The Changing ZPA for Mathematics Assessment

Given that NESA is not only recommending, but is, indeed, mandating a particular style of assessment task, it is notable that this injunction offers somewhat nebulous indications of what an acceptable assessment task might be. Indeed, the description appears to be rather more explicit when defining what the assessment task is *not*. For this task, NESA has, in effect, offered a well-defined ZFM - one that excludes tasks that bear the characteristics of a formal written examination. The ZPA, on the other hand, comprises a series of suggestions, which the school is not obliged to follow (Figure 6.1).

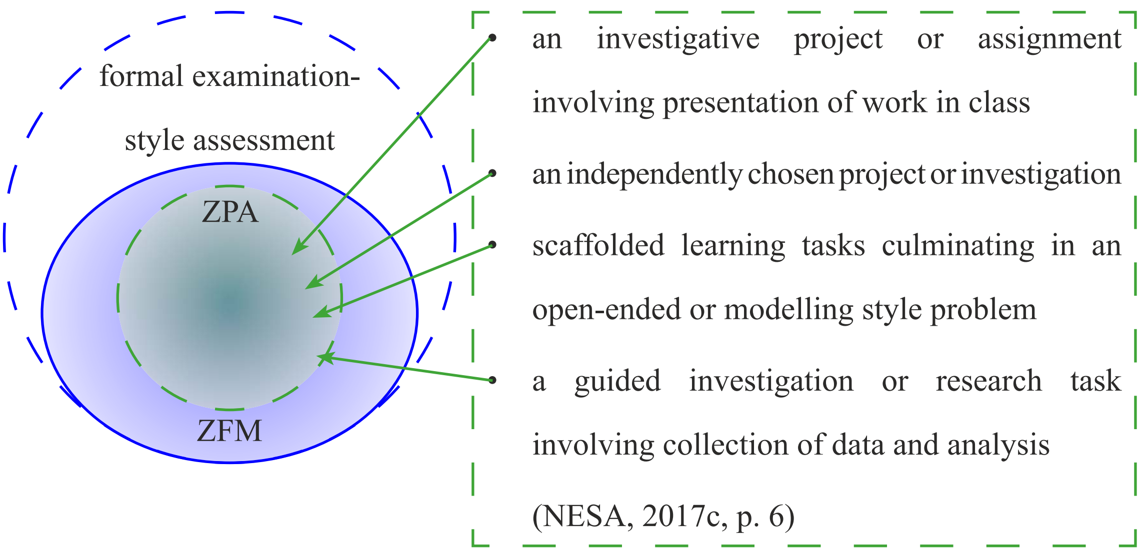


Figure 6.1. ZFM/ZPA configuration for the new NESA-mandated assessment task.

With such vague and limited criteria, the case for requiring the assessment task to exhibit particular characteristics appears to be relatively poor; and while it may be likely that students will utilise mobile devices and mobile technologies in producing this assessment artefact, there is little incentive to require the students' engagement to exhibit elements of authenticity.

Indeed, the lack of specificity regarding characteristics that must be present in this assessment task demonstrates that, while there is an appreciation that examinations offer a limited view of a student's accomplishments, there is as yet no assessment mechanism that is considered to be universally sufficient to fill this void. The system's reliance on teachers to invent such a mechanism for the assessment of their own students suggests a shift in the power structures in mathematics education. In effect, the establishment of this loosely-defined assessment task as a mandatory component of a high-stakes assessment regime indicates that NSW mathematics educators are being offered the opportunity to use their own experience and ingenuity to "control curriculum [and] student assessment", as their Finnish counterparts already do (Sahlberg, 2015).

6.2. Creativity and Conformance

With seven separate case studies, it is significant that the collective experience suggests a stance that is commonly held: that is, the expansion of the Zone of Free Movement (ZFM) is less suitable for students who are either lower-achieving or behaviourally immature. In particular, it was noted that the devices themselves presented work in such a way as to require higher levels of comprehension in order to access the learning. For these students, the teachers tended to employ mobile intensive pedagogies in such a way as to discourage exploration, offering well-defined and prescriptive tasks that would guide students' actions and, to the extent possible, prevent students from straying.

It is therefore evident that teachers' understanding of what constitutes "mobile learning" encompasses a plethora of options, and if we consider the case study teachers' experience, very few of those options would be categorised as "seamless learning". With a mathematics syllabus that defines what learning is valued, it is unclear how teachers can reasonably justify a transformative pedagogy that allows students to "explore, identify, and seize boundless latent opportunities that his/her daily living spaces may offer, rather than always being inhibited by externally defined learning goals and resources" (Milrad et al., 2013). Such a view of valued learning, with its apparent promotion of loosely defined goals, necessarily assumes that the valued learning will occur irrespective of the students' own abilities, preferences, and motivations; and in the case study schools, it was invariably the higher-achieving students who were expected to be able to profit from this way of working.

However, the data suggest that it may be possible to use this idea to support technology-enabled mathematical explorations for a larger proportion of students. This proposition stems from findings from the highly academically selective Elm Park High School, which chose not to promote mobile learning with its lower-achieving classes. Given that this was the case, questions must arise regarding whether or not the students in those classes would yet have been considered to be mathematics high achievers if they had attended a normal comprehensive school. Under those circumstances, would those students have been offered the opportunity to engage with mathematics in ways of their own choosing? Is the choice to withhold such a teaching and learning method from these students merely a function of local expectations?

6.2.1. Curricular Considerations

Questions regarding academic rigour, and the need to conform to syllabus requirements, raise issues regarding whether it is in fact reasonable to expect particular outcomes from student explorations. The unpredictable nature of such a pedagogical approach suggests that it is not wholly compatible with a curriculum structure that defines, in great detail, what is meant by “valued learning”. There is therefore something of a conundrum for teachers who are, essentially, obliged to teach the syllabus. In order to fulfil this duty, learning experiences must be orchestrated to guide student explorations towards specific goals.

It is this dilemma that sees an appreciation of the value of mobile learning transformed into mobile pedagogies that exhibit low levels of authenticity (Kearney et al., 2012). Mobile pedagogies that differ little from teaching methods employed in a pre-mobile-learning era are justifiable for their conformance to traditional academic expectations of school, while those that offer “authentic” learning, as guided by the student, are apt to lead down unexpected and unsanctioned rabbit holes - learning that may well be valuable, but not necessarily as valued by the education system within which all parties operate.

Thus it can be seen that, with a prescriptive and ambitious mathematics curriculum, Milrad et al.’s “seamless learner” cannot be an average student. The limiting nature of time constraints affects students' learning, with trade-offs evident when considering the relative weight given to syllabus coverage and authentic exploration. In a rigid curricular structure, the students who could be classified as "quick learners" may, at the school's discretion, be offered the opportunity to truly engage with the authentic learning, as a preferred alternative to marking time whilst other students are continuing on their learning journey; but it may not be so reasonable to expect struggling students to have enough time to engage with both the curriculum and the self-directed learning.

The negotiation of this trade-off has seen schools experiment with a "stage not age" model (e.g. Heppell, 2017) through which students choose to engage with curriculum that is developmentally appropriate for them. Such a curricular structure, whilst currently relatively novel, has already been implemented in Australian schools (e.g. Templestowe College, 2017). Its appeal lies in its fluidity, and its potential to support authentic learning experiences irrespective of the students' abilities relative to their similarly-aged peers.

6.2.2. Valued Learning

It is evident that mobile learning is present on all sides of the juncture between changing pedagogies and changing assessments. The findings of the present study make it clear that mobile learning is currently being used to support traditional teacher-centred direct instruction, as well as student-centred exploration. The findings also demonstrate that teachers are wary of the implications of divergent assessment mechanisms - with examinations continuing to feature as a major player in mathematics assessment, juxtaposed against project-based assessments that will soon be both mandatory and high-stakes. From this perspective, is almost as though the subject of "mathematics" is being split into two separate streams, with limited overlap between the "pure mathematics" that is done for its own sake, and the "applied mathematics" that is valued for its usefulness for solving a real-world problem (Pollak, 2011; Riskin, 1999).

With experience and, possibly, cultural inertia guiding teachers' pedagogical choices, it is unsurprising that teachers' understanding of the relative importance of different aspects of mathematical teaching and learning is biased in favour of the skills and actions that have, to date, proven to be successful for the "pure mathematics" assessments of the past. In particular, it was notable that an "ability to follow instructions" was considered to be paramount for success in mathematics examinations, with case study teachers rating it as being a skill of greatest importance. Such a viewpoint suggests an appreciation of the characteristics of the assessment mechanism: there is no value in being original, or in offering an unsought idea; the examination communicates precisely what is required, and the hope and expectation is that the student will respond with an answer that is identical to one that might be given by the teacher.

Thus the introduction of the project-based assessment poses the question of how the characteristics of "valued learning" are going to change. Indeed, in some situations, it may well be the case that these characteristics change very little. As an example, the ability to follow instructions is a skill that is highly transferable to assessment mechanisms that are not examination based, as it is equally valid and important for interpreting the grading rubrics that may be used for determining the sophistication of a mathematics project. In particular, it can be seen that International Baccalaureate students are obliged to produce work that will grade well against the rubrics offered for the judging of the Maths Exploration task.

However, it is equally evident that there are circumstances under which currently valued skills could begin to see a reduction in their importance. The creation of an original artefact may, indeed, value personal ingenuity and creativity over the student's "ability to follow instructions"; and changing characteristics of assessment tasks will mark any such shifts in what is considered to be important for students' development.

6.2.3. The Re-Evaluation of Valued Skills

With the creation of novel assessment mechanisms to appraise students' attainments in a changing paradigm for mathematical achievement, it is clear that skills that have been fundamental to the demonstration of competence will make way for skills that have not, to date, been so highly valued. Indeed, it is evident that the intention of the changing assessment regime is to make it clear that significant changes are being made to the set of valued skills.

The use of mobile technology to support mathematical thinking is a change with far-reaching implications, within which exists a recognition that distributed cognition through technology is fundamental to how professionals use mathematics in solving real world problems. While this authentic use of mathematics to make sense of the world may be appropriate for developing students' mathematical skills, the authenticity that is fundamental to this approach redefines assessment as a more subjective exercise, with judgements based on how closely the product resembles something that is competent and usable.

In considering Mislevy's (2013) argument that assessments "do not simply measure existing qualities ... they cause those qualities to exist", it can be seen that the project-based assessment methodology defines a set of characteristics that are now, more than ever, valued for mathematical achievement. Indeed, we may use this idea to supplement Berry and Adamson's (2011) enumeration of the functions of assessment. To the goals of "external accountability, competitive selection and diagnosis of strengths and weaknesses in learning", we may add "redefinition of the learning that is valued"; and thus position mathematics assessment both as a creator of momentum for driving pedagogical change, as well as an expression of the goals of a mathematical education.

6.3. The Interplay Between Mobile Learning and Assessment

The present study has noted the bi-directional nature of the relationship between mobile learning and assessment in secondary mathematics teaching and learning. In short, we have seen how, in the case study schools, assessment influences the kind of mobile learning that is promoted in maths class, with high achievers offered more opportunities to use mobile devices in an authentic way, and with student-centred mobile device usage generally considered to be less appropriate for students who are in a lower stream. We have also seen how mobile learning influences assessment, with the creation of supplemental assessment tasks that allow students to use technology to demonstrate what they can do.

On the surface, there does not appear to be significant overlap between these two ideas. The former discusses when, and for whom, teachers deem mobile learning to be appropriate; and the latter considers the assessment of the learning after it has occurred. Indeed, it can be seen that what is meant by "assessment", and indeed potentially "mobile learning", differs in these two circumstances. To be clear, assessments that are conducted to place students in streamed mathematics classes have tended to take the form of examinations - a proposition that differs markedly from assessment methods that would value distributed cognition. Likewise, the nature of the mobile learning that is used in class is not necessarily relatable to the use of mobile technology to produce an assessment artefact.

Therefore what we are seeing appears to be a multi-dimensional widening of what is valued in school mathematics. It demonstrates the applicability of different kinds of learning, and different kinds of assessment, for the valuing of different facets of a mathematical education.

With students being streamed for mathematics classes - and hence mobile learning - based on their results in examinations, it can be seen that the development of traditional mathematical competencies is still foundational to the way in which school mathematics is perceived. In the case study schools, it was evident that teachers tended to promote the skills that would help students to succeed in examinations, implying an appreciation of the importance of students being able to demonstrate their learning under examination conditions.

Thus, despite the limitations of the assessment instrument, the examination remains foundational to the assessment process, offering broad indications of students' powers of reasoning, comprehension, computational fluency, and work ethic. The case study teachers' choice to offer more authentic representations of mobile learning to students who possess these competencies strongly suggests that such traditionally valued characteristics are considered necessary for success in teaching and learning with student-centred technology.

It may therefore be inferred that teachers in the case study schools saw the benefits of "authentic" learning with mobile technology, as described by Kearney et al. (2012); but considered that these benefits would only outweigh any potential negatives when the class exhibited certain characteristics - characteristics which could be inferred, to some extent, by the students' achievement in an examination. Thus the establishment of students' learning dispositions was considered to be hierarchical, with authentic student-centred use of mobile technology being considered to require sturdy foundations in prior mathematical experience, academic aptitude, and a highly developed work ethic - what Patrick at Chesham House called a "good attitude". A further progression along this continuum would, in turn, see students being offered the opportunity to engage with authentic tasks, and finally to demonstrate their learning under authentic conditions (Figure 6.2).

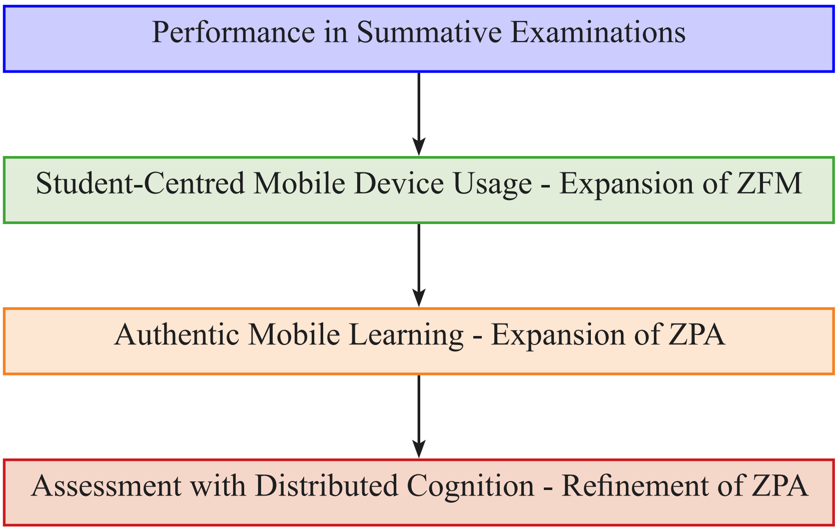


Figure 6.2. Hierarchy of teaching and learning successes culminating in engagement with authentic assessment.

With such a structure for choices surrounding the adoption of mobile pedagogies, it can be seen that mobile learning, in its current form, is being book-ended with two different assessment strategies - a pre-assessment that determines the student’s grasp of curricular content, and a post-assessment that offers the student the opportunity to demonstrate what they can do with the aid of a mobile device. While it is impossible to judge from the present study, being limited in both time frame and in the number of participating schools, whether such a structure is in fact necessary, the fact of its presence in some form in all of the case study schools does indicate that it is a structure that schools currently tend to find workable. Indeed, analogies may potentially be drawn with the Count Me In Too assessment tool, which specifies a series of steps which must occur in the development of mathematical understanding. It would be worthwhile investigating whether a similarly structured series of steps is in fact necessary for student development in order to reap the benefits of mobile learning, or indeed mobile device usage for working with authentic mathematical problems; and if so, whether an assessment of a student’s instrumental mathematical understanding is in fact an efficient method for determining readiness.

6.4. Implications for Pure Mathematics

With rapid changes to the mathematical competencies that are needed for participation in a changing workforce, values associated with school mathematics are likewise in a state of flux. Recognition that assessment must change in order to prioritise the acquisition of skills that are valued in the 21st century has seen the issuing of directives regarding assessments that are, in combination, high-stakes, mandatory, and loosely defined.

For mathematics, such a combination of characteristics is both curious and challenging. In a sense, the assessment mechanism does not appear to value what school mathematics has traditionally valued - formalism and elegance, conciseness and preciseness. It is a potential game-changer for the study of mathematics, turning it from a focus on representations that are abstract and perfect, and grounding it in messy, real-world, authentic use cases such as projects, investigations, and modelling.

Thus, given that NESA's assessment task suggestions appear to favour real-world problems, it would be well to consider whether or not projects in pure, abstract mathematics may be a possibility, and whether such project work would be both practical and satisfactory for the NESA assessment requirement. As with any proposed change to an established culture, proponents of the status quo must be considered; and it is evident that the change in assessment method affects all senior mathematics students, including those for whom pure mathematics is the preferred mode of study.

With mobile technology being used to engage with problems in pure mathematics in a number of the case study schools, it is evident that the choice to produce an assignment in pure mathematics is a real possibility. However, unlike mathematics applied to authentic contexts, pure mathematics operates under a fundamentally different paradigm, the assessment of which demands absolute correctness. This "correctness" requirement is not generally an issue for the assessment of a traditional mathematics examination, as correct responses are pre-determinable, and each student's work would be graded according to its conformance to the responses that are considered to be acceptable. However, the complexity of the grading inevitably increases when there is an error in the student's submission; and such errors may then be classified according to (possibly subjective) notions regarding the importance of the skill that the student apparently did not demonstrate.

At this stage, it may be argued that the accepted practice of applying a rubric to determine the relative weight of an error in reasoning, demonstrates that mathematics assessments are already being graded through subjective judgement. However, while this may be the case for examination practice, a question in an examination naturally defines the extent of the responses that might exhibit shades of correctness. Thus, for any one examination question, it should be possible to specify all of the paths that students may take in order to be entitled to partial credit.

In considering the grading of original project work in pure mathematics, it is evident that the determination of shades of correctness for a problem of interest to the student differs fundamentally from the grading of a response to a well-defined and well-understood examination question. If few limits are applied to the specification of a mathematical project, it is clear that it would be non-trivial to ascertain correctness, and considerations of incorrectness would be likewise demanding of teacher time and effort.

The issue, therefore, is whether creative endeavours in pure mathematics are compatible with the constraints surrounding school grading practices. In this problem space there is some suggestion that, while technology is potentially of benefit to a student in developing an idea in pure mathematics, it is not actually possible to create a generally applicable technological solution for the purposes of deciding whether the student's mathematical logic is in fact correct. David Hilbert's "Decision Problem" and the associated Church-

Turing thesis (Hilbert and Ackermann, 1928, as quoted in Church, 1936 and Turing, 1936) offers some insight into why the use of today's technology for this purpose is impossible. While it may, of course, be possible for a human to surpass a computer's ability to verify the validity of a student's assertions, the non-algorithmic nature of this problem means that it is difficult to estimate the amount of time and effort required of the teacher. Thus, given the attendant time constraints, it must be assumed that the grading of such project work in pure mathematics can become an impractical task.

However, the nature of this limitation gives rise to other potential effects of human ingenuity. One such possibility, suggested by a colleague in the School of Mathematical and Physical Sciences at UTS, is to require the student to produce at least two proofs that lead to the same conclusion. The potential for mobile technology to be of service in demonstrating at least one of these proofs offers a tangible, authentic use case in which mobile device usage can benefit students in their creation of project work in pure mathematics.

6.5. Future Directions

Despite the limited nature of the present study, a multitude of different implementations of mobile learning in mathematics were observed, with each being tailored specifically to the school's particular culture and circumstances. We were fortunate to observe such variety and we are extremely grateful to the schools for sharing their experience.

With such diversity in school types and cultures, it is possible to tentatively generalise in areas where the results appeared to exhibit some consistency across all of the case studies. However, it is evident that this study is not sufficient for determining causality, or indeed to back up assertions of any correlation. Its purpose was simply to investigate examples of practice, to uncover patterns in how mobile learning is currently being implemented and to observe how learning is assessed and valued.

It is evident that there are significant impracticalities inherent in determining whether any of the results in this study are universally applicable; and it must be said that it would be absurd to assume that any set of case study observations, however large, would comprehensively describe the experience in all schools. However, it should be both possible and interesting to see how practices at schools, including but not limited to these seven case study schools, evolve over time.

6.5.1. The Management of Mobile Learning Experiences and Opportunities

As a primary consideration, it would be well to find out if, and how, schools change their management of students' mobile learning experiences. Examples of evolution in practice have already been seen, with Moorgate Secondary College introducing an initiative to restrict access to the iPad App Store for students entering the school in Year 7.

Future questions in this space might include:

- Would schools choose to manage mobile device usage more closely, or would they discover that students are arriving in Year 7 having already developed the desired behaviours?
- Would mobile devices of the future be more easily configurable for oversight and management, irrespective of whether the devices are all of the same type, or indeed would future social practices see a move towards education in methods of self-regulation in preference to censorship?
- If it were, in fact, possible to restrict all students' devices in such a way, then would schools choose to use it, and if so what form would the restriction take?

Questions regarding device restrictions, whilst not directly related to mathematics and assessment, are significant because the case study schools currently demonstrate that the choice to offer device-enabled activities is dependent upon students' disposition and achievement in mathematics. The one school where the relationship did not exist in this form was Moorgate Secondary College, which implemented restrictions on software (as opposed to device access) as a matter of course for all Year 7 students, thus obviating the need to assess for behavioural maturity and mathematical achievement.

Given that Moorgate has been able to devise such an alternative solution, it is possible that the observed influence of assessment results upon teachers' choices to engage with student-centred mobile pedagogies is a temporary phenomenon. While restrictions on student behaviour and student actions in class are well-understood as aspects of classroom management, the use of assessment outcomes to gauge the appropriate level of restriction upon the students' ZFM is a practice that may change over time. It would be expected that, given the rate of change in the capabilities of mobile devices, restrictions on mobile device usage will likely change also; and in this area there would be much to be learned, in and around the social aspects of device management.

6.5.2. Mobile Learning, and What It Means to Engage

Since the present study has already noted significant variety in what teachers consider to be "mobile learning", there is great potential for educational experiences in this space to diverge and multiply. With the education system devolving responsibility for some high-stakes assessment mechanisms to individual teachers' experiences, beliefs, and ingenuity, the nature of the learning will likewise be determined by teachers, and thus bear the marks of teacher preference.

Mobile learning offerings, as observed in this study, ranged from electronically delivered textbooks and past papers, through to in-class quiz applications, flipped learning, and project work. With a general tendency to favour more structured learning tasks for lower-achieving students, it would be interesting to see if schools begin to realise the potential for mobile learning to support more flexible models of school; and if so, what forms these models might take. Since current implementations of de-streaming include differentiation through the provision of structure (or lack thereof), as demonstrated by Moorgate Secondary College, as well as pedagogies based on the "Stage not Age" idea, the education system of the future may well see a plethora of competing options for what is considered to be a teaching and learning structure that caters to each student's unique Zone of Proximal Development. Indeed, it is likely that teachers will observe external implementations, and select parts of each to form a unique blend that makes sense for their own circumstances; in which case it would be interesting to note how teachers become aware of relevant examples of practice. Future research could then seek to understand, not only the ways in which teachers construct learning experiences, but how they determine the suitability of these experiences for the different learners in their care.

6.5.3. The Assessment of Mobile Technology-Enabled Distributed Cognition

The use of mobile technologies for mathematics education sees teachers faced with a choice between the learning that is known to be valued in examinations, and the mathematical thinking that is particularly supported by the use of the device. With respect to the former choice, it would certainly be of great interest if a study could be conducted to determine the effectiveness of a technology-enabled pedagogy for supporting students through learning for examinations. However, given the pace of change in what mobile learning can offer, coupled with the breadth of the idea that is "mobile learning", it would be difficult to imagine a study in the foreseeable future that will offer a definitive answer in this regard. There is a real danger that software and hardware upgrades would pre-determine the irrelevance of the results of such a study, even before they are published, and replication of the conditions of the study would be very difficult while the technology continues to rapidly improve.

Thus, while the employment of mobile pedagogies for examination preparation would be highly relevant for teachers' practice, it would be well to consider other ways of assessing the effects of this pedagogical approach. In particular, while the present study has sought to discover ways in which schools are currently assessing student work that is produced with the aid of technology, it is clear that there is great scope for pedagogical knowledge to increase in this space. Will schools adopt a highly structured project work model similar to that observed at Osterley High School, or will they give students the freedom to investigate mathematics of personal interest, as observed for the International Baccalaureate students at Bermondsey College? Will schools value creativity in high-level pure mathematics, as seen at Elm Park High School, or indeed will they outsource some assessment tasks to external providers, as seen at Chesham House?

Questions regarding how assessments might change to include the production of work with the aid of technology must then also consider what the implications would be for teachers' grading practices. With a historical preference for grading for correctness, attention must be given to mathematics teachers' attitudes towards the purpose and value of subjective grading, and the learning curve that experienced teachers may need to overcome in order to be able to assess in this way.

In particular, it would be interesting to see if all teachers will willingly reconcile mathematics with subjectivity. Such a line of questioning could lead to research into how teachers choose to specify an assessment task that simultaneously suits their perceptions of what mathematics is about, and permits students to use mobile technology to support their thinking. With different conceptions of what it means to demonstrate mathematical competence, patterns may emerge that define schools and teachers for what they value and how they assess; and future research could then be directed towards analysing the paths taken towards the consolidation of ideas, or the effects of any divergence in practice.

Finally, the changing of the assessment mechanism away from the rigid structure of the examination introduces a range of problems. The need to consider such issues as academic integrity, an appropriate level of mathematical sophistication, and the determination of the accuracy of the outcome, changes what is expected of the teacher whose job it is to determine the quality of the students' work. Further research could then seek to investigate how teachers cope with this assessment structure, and whether the importance of any of these attributes is diluted for the sake of practicality.

6.6. The Purpose of a Mathematical Education

In response to our original rhetorical question regarding what constitutes mathematical attainment, it can be seen that Skemp's (1976) distinction between "relational" and "instrumental" mathematical understanding remains as relevant as ever. Indeed, since the advent of ubiquitous computational power, it may be argued that the skill of being able to solve mathematics problems instrumentally is becoming increasingly obsolete.

It then remains to question what it is that we really do value in mathematical attainment. If, in the real world, we do not actually value people's ability to perform calculations without the aid of a computer, then what is the purpose of teaching such a skill to our students? Is it simply a throwback to tradition, or does it serve a higher purpose - a structuring of our thought processes, and a developing of students' facilities for problem solving and clarity of communication?

With the assessment of mathematics currently comprising, in large part, mechanisms that are based on an examination-style format, it is clear that our society continues to value demonstrations of instrumental competence, despite an acknowledgement that computers can generally do it faster than we can, and with greater accuracy. Thus, with examinations occupying a highly privileged position in mathematics assessment, we have sought ways of asking questions that require more ingenuity and understanding, and which are less amenable to being solved by "rules without reasons". To this end, the Webb Depth-Of-Knowledge (Webb, 2002, summarised in DuFour and DuFour, 2015) and MATH (Ball et al., 1996) taxonomies both offer suggestions for how such questions might be structured.

However, it is evident that such a reliance on good examination questions for ascertaining the level of students' mathematical understanding still tends to value demonstrations of competence that are, whilst not necessarily instrumental, not necessarily authentic either.

Due to rapid changes in the technology that students will be expected to utilise to solve mathematics problems after they leave school, it would be remiss of systemic mathematics education to ignore the reality of a world where mobile technology is commonplace. A mathematics education must therefore promote and actively value the skills that students will need in order to use mobile technology to support their mathematical thinking.

This leads to an appreciation that what is valued in mathematical thinking is rapidly changing, in ways that increasingly cannot be assessed under examination conditions. While there is no suggestion that the examination is obsolete - and it would be foolhardy indeed to discard the teaching profession's collective experience with examinations in favour of a focus on something new - there is yet a real need to invent ways to assess these new ways of thinking.

We shall therefore consider Archbald and Newmann's (1988) idea of "value beyond evaluation", demonstrating the difficulties inherent in assessing authentic mathematical thinking, in combination with Mislevy's (2013) argument that assessment is also a communication mechanism that will "cause those qualities to exist". Together, these two ideas suggest that, while it may not be practical to expect assessments to give true indications of authentic understanding, just the act of attempting to assess authentically might go some way towards changing the way that teachers teach, as well as the way that students learn. It may, indeed, be beneficial just to specify assessments that value particular qualities, even if those qualities cannot really be assessed.

It is possible that this situation is, in fact, not unlike the use of the Webb Depth-Of-Knowledge and MATH taxonomies for the purposes of creating assessment tasks that test for Skemp's "relational understanding", because upon further examination it can be seen that the purpose of such an assessment is no longer simply to determine the extent of student learning. Rather, such examples appear to serve more as a deliberate guide for teacher actions, so that students would then be exposed to the learning activities that teachers believe would lead towards a more favourable assessment outcome.

Papert (1998) asserted that "the one really competitive skill is the skill of being able to learn. ... We need to produce people who know how to act when they're faced with situations for which they were not specifically prepared". If we accept Papert's recommendation, then it is clear that, as an education system, we can justify the specification of assessment tasks that value skills such as the authentic use of mobile technology to learn mathematical concepts and solve mathematical problems. Such assessments must value the production of responses that are not taught; and indeed, the juxtaposition of the case study schools' explicit assessment task notifications against Papert's call demonstrates the gulf between what is valued by examinations, and what is useful for real-world competence. The problem, therefore, would be how to define assessments on a larger scale for such a purpose, in order to communicate these values to students via the actions of their teachers. Whether such assessments determine students' capacity to solve real-world problems is then potentially secondary to their purpose as a demonstration to teachers that such thinking would be the outcome of value.

In revisiting Charles Lovitt's wonderful lesson in the real-life, authentic mathematics of gambling probabilities, it can be seen that, while it may be impossible to assess this learning in a way that distinguishes it from direct instruction, it is clear that the learning is yet of significantly more value - the "value beyond evaluation" that drives the choice to engage with authentic pedagogies. Existing examples such as these show that it may not really matter whether it is possible to definitively establish the student's subsequent depth of understanding. As long as it is possible to conscript the assessment mechanism for the purposes of demonstrating such value to the teacher, there will be a reason to engage with the learning.

Like all authentic assessment, the determination of students' ability to use mobile devices in a sophisticated way to support mathematical thinking must exhibit elements of non-determinism and subjectivity. If we are to value such a skill, it will be necessary for mathematics assessment to evolve towards an appreciation that absolute assessment outcomes are of secondary importance. Such a shift in thinking can then pave the way for the creation of assessment mechanisms that value what it is that society, and professions that work with specialist mathematics, value in the mathematical foundations being built at school; and since such mechanisms are likely to pose practical implementation difficulties, their introduction must be coupled with an acceptance that the outcomes being sought are larger, and of greater significance, than objectively defensible marks and student ranking.

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Appendices

A-1. HREC Ethics Approval

From: Research Ethics <research.ethics@uts.edu.au>
To: Anne Prescott <Anne.Prescott@uts.edu.au>, Pauline Kohlhoff <Pauline.W.Kohlhoff@student.uts.edu.au>, Research Ethics <research.ethics@uts.edu.au>
Subject: HREC Approval Granted - ETH16-0476
Date: Monday, August 15, 2016 11:50 AM
Size: 15 KB

Dear Applicant

Thank you for your response to the Committee's comments for your project titled, "Implications of mobile intensive pedagogies for secondary school mathematics assessment practices". Your response satisfactorily addresses the concerns and questions raised by the Committee who agreed that the application now meets the requirements of the NHMRC National Statement on Ethical Conduct in Human Research (2007). I am pleased to inform you that ethics approval is now granted.

Your approval number is UTS HREC REF NO. ETH16-0476.

Approval will be for a period of five (5) years from the date of this correspondence subject to the provision of annual reports.

Your approval number must be included in all participant material and advertisements. Any advertisements on the UTS Staff Connect without an approval number will be removed.

Please note that the ethical conduct of research is an on-going process. The National Statement on Ethical Conduct in Research Involving Humans requires us to obtain a report about the progress of the research, and in particular about any changes to the research which may have ethical implications. This report form must be completed at least annually from the date of approval, and at the end of the project (if it takes more than a year). The Ethics Secretariat will contact you when it is time to complete your first report.

I also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

You should consider this your official letter of approval. If you require a hardcopy please contact Research.Ethics@uts.edu.au.

To access this application, please follow the URLs below:
* if accessing within the UTS network: https://rm.uts.edu.au
* if accessing outside of UTS network: https://vpn.uts.edu.au , and click on " RM6 – Production " after logging in.

We value your feedback on the online ethics process. If you would like to provide feedback please go to: http://surveys.uts.edu.au/surveys/onlineethics/index.cfm

If you have any queries about your ethics approval, or require any amendments to your research in the future, please do not hesitate to contact Research.Ethics@uts.edu.au.

Yours sincerely,

Professor Marion Haas
Chairperson
UTS Human Research Ethics Committee
C/- Research & Innovation Office
University of Technology, Sydney
E: Research.Ethics@uts.edu.au

A-2. Teacher Letter, Information Sheet, and Consent Form

UTS
UNIVERSITY OF TECHNOLOGY SYDNEY

INVITATION LETTER

IMPLICATIONS OF MOBILE INTENSIVE PEDAGOGIES FOR SECONDARY SCHOOL MATHEMATICS ASSESSMENT PRACTICES (UTS HREC APPROVAL NUMBER ETH16-0476)

Dear ………..

My name is Pauline Kohlhoff and I am a student at the University of Technology, Sydney.

I am conducting research into mathematics teaching and learning with mobile technologies (mobile phones, tablets, laptops), and would welcome your assistance.

The research is seeking to investigate mathematics assessment practices, and the ways in which they influence, and are influenced by, mobile technology use in secondary school mathematics. It will involve three semi-structured interviews over several months, analysis of some assessment artefacts, and up to three class observations. It should take no more than 4 hours of your time outside of your normal teaching load. I have asked you to participate because you have been recommended to me for your use of mobile technology in mathematics teaching.

This research has been funded by a grant from the Australian Research Council, and is for my Ph.D studies in mathematics education.

If you are interested in participating, I would be glad if you would contact me at Pauline.Kohlhoff@uts.edu.au, and/or my supervisor Associate Professor Anne Prescott at Anne.Prescott@uts.edu.au.

You are under no obligation to participate in this research.

Yours sincerely,

Pauline Kohlhoff

Pauline.Kohlhoff@uts.edu.au

NOTE:
This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: +61 2 9514 2478 Research.Ethics@uts.edu.au), and quote the UTS HREC reference number. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

INFORMATION SHEET - Teachers

IMPLICATIONS OF MOBILE INTENSIVE PEDAGOGIES FOR SECONDARY SCHOOL MATHEMATICS ASSESSMENT PRACTICES (UTS HREC APPROVAL NUMBER ETH16-0476)

WHO IS DOING THE RESEARCH?

My name is Pauline Kohlhoff and I am a student at UTS. My supervisor is Associate Professor Anne Prescott.

WHAT IS THIS RESEARCH ABOUT?

This research is to find out about how teachers who use mobile technologies (mobile phones, tablets, laptops) for secondary school mathematics teaching and learning, construct assessments to determine student achievement. It seeks to find out what teachers value in student learning and to investigate ways in which mathematics assessment might change.

IF I SAY YES, WHAT WILL IT INVOLVE?

I will invite you to participate in three 1-hour semi-structured interviews over several months. The interviews will be audio-recorded and transcribed. I will also ask you to show me some de-identified assessment artefacts. In addition, I will ask you to let me watch you teach up to 3 mathematics classes, during which I will take written notes only.

ARE THERE ANY RISKS/INCONVENIENCE?

There are very few if any risks. However, it is possible that some students will object to being observed.

WHY HAVE I BEEN ASKED?

You have been recommended to me for your innovative teaching practices. I would like to speak with you about your insights regarding the use of mobile technologies in mathematics classes, and how it might affect, and/or be affected by, mathematics assessment practices. I think these insights would be of great interest to other teachers.

DO I HAVE TO SAY YES?

You don't have to say yes.

WHAT WILL HAPPEN IF I SAY NO?

Nothing. I will thank you for your time so far and won't contact you about this research again.

IF I SAY YES, CAN I CHANGE MY MIND LATER?

You can change your mind at any time and you don't have to say why. I will thank you for your time so far and won't contact you about this research again.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact us at Pauline.Kohlhoff@uts.edu.au ([redacted]) or Anne.Prescott@uts.edu.au (02 9514 5406).

If you would like to talk to someone who is not connected with the research, you may contact the Research Ethics Officer via Research.Ethics@uts.edu.au, and quote this number: **ETH16-0476**

UTS
UNIVERSITY OF TECHNOLOGY SYDNEY

INFORMED CONSENT FORM - Teacher
Implications of mobile intensive pedagogies for secondary school mathematics assessment practices (UTS HREC approval number ETH16-0476)

I ____________________ agree to participate in the research project "Implications of mobile intensive pedagogies for secondary school mathematics assessment practices" being conducted by Pauline Kohlhoff (Pauline.Kohlhoff@uts.edu.au;) of the University of Technology, Sydney for her degree of Doctor of Philosophy. Funding for this research has been provided by UTS and a grant from the Australian Research Council.

I understand that the purpose of this study is to investigate the use of mobile technologies (mobile phones, tablets, laptops) in school mathematics, and how the use of mobile technology influences, and is influenced by, mathematics assessment practices.

I understand that I have been asked to participate in this research because I use mobile technologies in my mathematics teaching. My participation in this research will involve my being interviewed three times over a period of several months, with each interview taking approximately one hour and recorded using an audio recording device. I will also be asked to provide copies of de-identified assessment artefacts. In addition, I will be asked for the opportunity to observe my teaching when using mobile technologies, and that written notes will be taken in such cases. I understand that the researcher will abide by my judgement and recommendations regarding any protocols for the observation.

I am aware that I can contact Pauline or her supervisor Associate Professor Anne Prescott if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish, without consequences, and without giving a reason.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

I agree that Pauline has answered all of my questions fully and clearly.

____ ____/____/____
Signature (participant)

____ ____/____/____
Signature (researcher or delegate)

NOTE:
This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: +61 2 9514 2478 Research.Ethics@uts.edu.au) and quote the UTS HREC reference number. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

A-3. Principal Letter and Information Sheet

UTS
UNIVERSITY OF TECHNOLOGY SYDNEY

IMPLICATIONS OF MOBILE INTENSIVE PEDAGOGIES FOR SECONDARY SCHOOL MATHEMATICS ASSESSMENT PRACTICES (UTS HREC APPROVAL NUMBER ETH16-0476)

Dear ……..,

My name is Pauline Kohlhoff and I am a student at the University of Technology, Sydney.

I am conducting research into mathematics teaching and learning with mobile technologies (mobile phones, tablets, laptops), and would welcome your assistance.

The research is seeking to investigate mathematics assessment practices, and the ways in which they influence, and are influenced by, mobile technology use in secondary school mathematics. I would like to request your permission to conduct part of this research at your school. In particular, …….. has been recommended to me for their use of mobile technology in mathematics teaching. I spoke with …….. last year and they have indicated that they would be willing to let me observe some of their classes.

The research will involve up to one further semi-structured interview, analysis of some assessment artefacts, and up to three class observations. It should take no more than one more hour of ……..'s time outside of their normal teaching load.

This research has been funded by a grant from the Australian Research Council, and is for my Ph.D studies in mathematics education.

If you are happy for me to proceed, I would be glad if you would contact me at Pauline.Kohlhoff@uts.edu.au, and/or my supervisor Professor Sandra Schuck at Sandy.Schuck@uts.edu.au.

You are under no obligation to participate in this research.

Yours sincerely,

Pauline Kohlhoff

Pauline.Kohlhoff@uts.edu.au

NOTE:
This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: +61 2 9514 2478 Research.Ethics@uts.edu.au), and quote the UTS HREC reference number. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

UTS
UNIVERSITY OF TECHNOLOGY SYDNEY

INFORMATION SHEET - Principal, ……..

IMPLICATIONS OF MOBILE INTENSIVE PEDAGOGIES FOR SECONDARY SCHOOL MATHEMATICS ASSESSMENT PRACTICES (UTS HREC APPROVAL NUMBER ETH16-0476)

WHO IS DOING THE RESEARCH?

My name is Pauline Kohlhoff and I am a student at UTS. My supervisor is Professor Sandra Schuck.

WHAT IS THIS RESEARCH ABOUT?

This research is to find out about how teachers who use mobile technologies (mobile phones, tablets, laptops) for secondary school mathematics teaching and learning, construct assessments to determine student achievement. It seeks to find out what teachers value in student learning and to investigate ways in which mathematics assessment might change.

IF I SAY YES, WHAT WILL IT INVOLVE?

I will request the opportunity to observe up to 3 mathematics classes being taught by …….., during which I will take written notes only. I will also invite …….. to participate in one more semi-structured interview, which will be audio-recorded and transcribed. In addition, I will ask …….. to show me some de-identified assessment artefacts.

ARE THERE ANY RISKS/INCONVENIENCE?

There are very few if any risks. However, it is possible that some students will object to being observed.

WHY HAVE I BEEN ASKED?

…….. has been recommended to me for their innovative teaching practices. I would like to observe their use of mobile technologies in mathematics classes, to inform my understanding of their insights into how mobile technology use might affect, and/or be affected by, mathematics assessment practices. I think these insights would be of great interest to other teachers.

DO I HAVE TO SAY YES?

You don't have to say yes.

WHAT WILL HAPPEN IF I SAY NO?

Nothing. I will thank you for your time so far and won't contact you about this research again.

IF I SAY YES, CAN I CHANGE MY MIND LATER?

You can change your mind at any time and you don't have to say why. I will thank you for your time so far and won't contact you about this research again.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact us at Pauline.Kohlhoff@uts.edu.au ([redacted]) or Sandy.Schuck@uts.edu.au (02 9514 3999).

If you would like to talk to someone who is not connected with the research, you may contact the Research Ethics Officer via Research.Ethics@uts.edu.au, and quote this number: **ETH16-0476**

A-4. SERAP Approval

Education
Public Schools

Mrs Pauline Kohlhoff
[redacted]

DOC17/522058
SERAP 2017155

Dear Mrs Kohlhoff

I refer to your application to conduct a research project in NSW government schools entitled *Implications of mobile intensive pedagogies for secondary school mathematics assessment practices*. I am pleased to inform you that your application has been approved.

You may contact principals of the nominated schools to seek their participation. **You should include a copy of this letter with the documents you send to principals.**

This approval will remain valid until 30-May-2018.

The following researchers or research assistants have fulfilled the Working with Children screening requirements to interact with or observe children for the purposes of this research for the period indicated:

Researcher name	WWCC	WWCC expires
Pauline Kohlhoff	WWC0045045E	13-Nov-2019

I draw your attention to the following requirements for all researchers in NSW government schools:

- The privacy of participants is to be protected as per the NSW Privacy and Personal Information Protection Act 1998.
- School principals have the right to withdraw the school from the study at any time. The approval of the principal for the specific method of gathering information must also be sought.
- The privacy of the school and the students is to be protected.
- The participation of teachers and students must be voluntary and must be at the school's convenience.
- Any proposal to publish the outcomes of the study should be discussed with the research approvals officer before publication proceeds.
- All conditions attached to the approval must be complied with.

When your study is completed please email your report to: serap@det.nsw.edu.au
You may also be asked to present on the findings of your research.

I wish you every success with your research.

Yours sincerely

Production Note:

Signature removed
prior to publication.

Dr Robert Stevens
Manager, Research
30 May 2017

School Policy and Information Management
NSW Department of Education
Level 1, 1 Oxford Street, Darlinghurst NSW 2010 – Locked Bag 53, Darlinghurst NSW 1300
Telephone: 02 9244 5060 – Email: serap@det.nsw.edu.au

A-5. Observation Schedule

- How is the teacher structuring this interaction?
    - What is the overall lesson plan?
    - How much time is spent on each part of the lesson?
    - What are the actions being performed by the teacher?
    - What does the teacher intend for the students to do?
    - Is any homework set?
- How does the teacher plan for student-centred mobile device usage?
    - Is it used as a direct substitute for an older technology (such as a textbook)?
    - Is it used for management?
    - Is it used for assessment?
    - Is it used for a learning activity that would have been impractical without the present technology?
- How do the students respond to the lesson?
    - Do the students understand the content, and what it is they are expected to do?
    - How does the timing of the lesson align with the amount of time students need to complete the activity?
    - Is the lesson pitched at an appropriate level of difficulty for the students?
    - Are the students interested and engaged?
    - Is student learning evident in their interactions with each other, and with the teacher?
- How do the students use the devices?
    - Is the learning prescriptive, or do students have the latitude to construct their own knowledge?
    - Are there difficulties with device usage?
    - Are the mobile devices used for any off-task activities?
- Is formative assessment evident in this interaction, and if so, what form does it take?
- Is any part of this lesson summatively assessed?

A-6. Post-Observation Debrief

- If a summative assessment occurred,
    - Does this assessment contribute to any grades?
    - If so, how much weight is accorded to this assessment?
    - How often do such assessments occur?
    - How are the results collated and analysed?
    - When do students receive the results?
    - Is the assessment only summative or is it also used for other purposes (e.g. for formative purposes)?
- If a formative assessment occurred,
    - What is the intention of the assessment?
        - Is it intended to help the students to learn?
        - Is it intended to help the teacher to plan subsequent lessons?
    - How are the results collated and analysed?
    - What does this assessment indicate about the students' learning?
    - How will this information be used?

A-7. Exploring Mathematics Program

0: Contents

1: Introduction

1.1 Synopsis

Exploring Mathematics (hereafter XM) is an elective semester course offered to Stage 5 (Year 9-10) students at Cherrybrook Technology High School. This document provides an over view of the XM course, its topics, and the formal assessments it includes.

1.2 Course rationale

To understand what the nature of this course, it helps to understand what it is not:
- This course is not about acceleration (learning content from years 11-12 in advance so that you will be more familiar with it when you encounter it in the future). In fact, topics in the Stage 6 mathematics subjects have been intentionally avoided so that they can be given their proper introduction in the Preliminary and HSC courses.
- This course consciously avoids the content and style of the enrichment courses designed by the Australian Mathematics Trust (*Euler*, *Gauss*, *Noether* and *Polya*). The content has been avoided since the majority of students enrolling into XM will have already completed these courses. The style has been avoided as XM intends to show that mathematics in general has much broader goals than being able to answer questions posed in a largely artificial context.
- This course is not like regular mathematics classes in its *classroom activities* or its *assessments*. In fact, there is a very conscious emphasis on branches of mathematics that are not understood through repetitive exercises, nor assessed in traditional examination formats.

By contrast, the goals of this course are:
- To introduce students to different areas of mathematics that they would not otherwise encounter or experience
- To cultivate students' ability to think in mathematically abstract terms
- To assist students in seeing and appreciating the ubiquity of mathematics

In other words, the purpose of this course is to *explore mathematics* in a cognitively intensive and engaging environment.

2: Course Content

Orientation

Since students have been so accustomed to studying mathematics in one particular format and style (as prescribed by the BOS mathematics courses), it is worthwhile devoting time to reorienting students to the fundamentally different approach of the course. Orientation should be included at the very beginning of the course to help students understand the unique goals of this course and the specific ways that those goals will be achieved.

2.1 Beauty & Mathematics

The title of this topic is intentionally ambiguous, intending to communicate both that "beauty is inherently mathematical" and "mathematics is undeniably beautiful".

Subtopics
- The Golden Ratio
  - The Golden Ratio
  - The Golden Rectangle
  - Fibonacci numbers, recursive sequences, Lucas numbers and Phi
- Music: Ratios and the Western Scale
- Four-Colour Theorem
- Symmetry (Line, Point, Helical, Scale)
  - Central inversion (point reflection = rotation)
  - Combining symmetries (2D spiral "rose", pinwheel tiling)

2.2 Fractals: The Mathematics of Self-Similarity

Scale symmetry and the golden spiral both pave the way to understand fractals. Many of the most beautiful fractals require computer generation to appreciate them fully, but there are several that are feasible and enjoyable to construct by hand. This topic will investigate some of these patterns.

Subtopics
- Fractals in nature
  - Rivers and ferns
  - The coastline paradox
- Simple fractal construction (detailed instructions kept separately from this program)
  - Sierpinski's triangle
  - Koch snowflake
  - Pythagoras tree
- Complicated fractal construction
  - Barycentric subdivision
  - Sierpinski's triangle through isosceles trapezia
  - Dragon curve
- Mandelbrot set (dynamic sequences / iterated function systems)
- Appolonian gasket

2.3 Set Theory: The Families of Mathematics

The infinitely repeating patterns of fractals lead into a discussion of things that do not end, but continue forever. To mathematically approach and articulate such abstract ideas, we need to first develop a robust understanding of the different categories of numbers that exist, as well as a language for describing the relationships between them. These categories are called sets, and the language describing them is set theory.

Subtopics
- Set terminology and notation
- Venn and Carroll diagrams
  - Two set arrangements
  - Poly-set arrangements
- Natural numbers, integers, rational numbers, real numbers, complex numbers, algebraic numbers, transcendental numbers…

2.4 Drawing Boundaries & Pushing On Them: Definitions and Undefinables

Equipped with a deeper understanding of the various kinds of numbers that mathematicians have defined, we can now address the topic of infinity.

Subtopics
- Is mathematics invented or discovered?
  - Philosophies of mathematics throughout history
- What is infinity?
  - A concept, not a number
  - Countable infinities versus uncountable infinities
- Cantor's diagonalisation proof
- Why are things "defined" or "undefined"? (e.g. division by zero)
- Counting Systems
  - Unary (tally)
  - Roman numerals
  - Arabic numerals and place value
  - Non-decimal bases (e.g. Binary, Hexadecimal)

2.6 Matrices: The Workhorses of Mathematics

In the previous topic, we traced the development of mathematics as a tool for communication and transaction. This introduces the idea of mathematics and calculation being used in the context of work. One of the most important structures for mathematical work is the matrix.

Subtopics

- Definition: abstracting a system of equations
- Elementary row operations and Gaussian elimination
- Matrix Multiplication
- Inverse of a matrix
- Determinant of a matrix

2.7 Cryptography: The Mathematics of Secrecy

One of the chief uses of mathematics in modern society is to keep secrets – namely, through the encryption of data. While these processes are intentionally concealed from users of credit cards and websites, they touch on a variety of interesting mathematical concepts and tricks which will be investigated in this topic.

Subtopics

- Caesar cipher
- One-time pads
- Symmetric (private key) vs. Asymmetric (public key) encryption
- Prime numbers
  - Euclid's proof for infinite primes
  - Primality tests (Fermat's Little Theorem, Wilson, AKS test)
- Enigma in WW1
- Random numbers
  - Pseudorandom and True random number generators
  - Linear Congruential Generator

2.8 Paradoxes: When Mathematics Doesn't Make Sense

In life, there are many things that seem counter-intuitive at first – but, once thought about carefully, do actually make sense (and often reveal something very interesting in the process). Mathematics is the same, and this topic will focus on mysterious and perplexing scenarios within it.

Subtopics

- Fallacies (false proofs)
  - $2 = 1$ (through division by zero)
  - $-1 = 1$ (through Pythagorean trigonometric identity)
  - $\sqrt{-1} = 1$ (through roots of unity)
  - All triangles are equilateral (through construction)
- Monty Hall problem
- Bridges of Konigsberg
- Unexpected geometry
  - The Shoemaker's Knife
  - Three intersecting circles
  - Morley's Trisection Theorem
  - Three square / right-angle problem
  - Missing squares
- Chaos Theory
  - Minutelabs interactive demos
- Benford's Law
- Look & Say Numbers
- Conway's Game of Life
- Coastline Paradox
- Zeno's Paradox
- Pisano Period
- Potato Paradox

2.9 Play: The Mathematics Behind Games

A fitting end to the course is to focus on a pastime that is universally enjoyed: games. Games are amazing in that they appeal to many people who dislike mathematics – despite the fact that it is virtually impossible to find a game without mathematics deeply woven into its rules and strategies.

Subtopics

- Sudoku
- Kenken
- Connect Four
- 2048
- Chess
- Rubik's Cube
- Monopoly
- Computer games
- Card games
- Prime Climb
- Set
- Minesweeper
- Watch out for Voldemort
- 2 on 1
- Dice Difference

3: Assessments

3.1 A note about XM assessments

Mathematics assessments are predominated by limited-time limited-resource algorithm/skill-focused tasks (in other words, formal examinations). The open nature of XM enables students to pursue areas of mathematics that do not fit so readily into these kinds of tasks. Therefore, the tasks below are intended to provide a contrast to the normal types of assessment found in a standard mathematics course.

For further details on these tasks (including specific task components and detailed marking rubrics), see the Assessment Outline.

3.2 Overview of tasks

Code	Name	Description	Weight
AT1	Electronic Journal	Students compose metacognitive reflections on topics covered during lessons.	15%
AT2	Artwork	This task is designed to follow the topics *Beauty & Mathematics* and *Fractals*. Students design and create a two-dimensional piece that illustrates their understanding of the role that mathematics plays in visual aesthetics.	20%
AT3	Set Theory Quiz	Short-response topic test designed to assess students' understanding of the concepts found in Set Theory.	20%
AT4	Video Composition	In groups, students design, direct and create a short video that explains a mathematical concept in an interesting and engaging way.	20%
AT5	Matrices Quiz	Short-response topic test that assesses students' ability to interpret and manipulate Matrices.	20%
	Class Participation		5%
			100%

4: Resources

4.1 Written resources

The table below lists some useful textbooks.

Title	Details
Inside Mathematics (10 Advanced) Sattler & White	Chapter 16 on "More Mathematical Investigations" includes some interesting tasks.
Mathematics for Australian Schools (10) Ganderton	Chapter 13 has useful material and exercises for teaching Matrices. The "construction sections" appended to each chapter are also varied and interesting.
New Century Maths (10 Advanced) Bootsma, Badger & Skene Spectrum Mathematics (10 Advanced) Priddle & Osborne Insight Mathematics (10 Advanced) Ley & Fuller	Before the introduction of the 5.1/5.2/5.3 Pathways syllabus, the Standard/Intermediate/Advanced courses in Stage 5 offered option topics for Advanced students. One of these options was Fractals. These textbooks have useful sections covering this topic.

4.2 Online resources

The table below lists websites that were used during the development or delivery of the XM course.

Address	Description
www.misterwootube.com/tag/exploremaths	This is the companion website that I created for the course. Here, I posted tasks for the class and students responded with their own thoughts and reflections.
www.youtube.com/numberphile	Numberphile produces videos covering a broad range of mathematical curiosities, explained by a variety of academics and mathematicians (primarily based in the UK). The channel provides a rich source of inspiration for a variety of interesting numbers and theorems.
www.youtube.com/vihart	Vi Hart's videos basically consist of her drawing doodles or comics that illustrate mathematical ideas with her voiceover in the background. Like Numberphile (above), her videos provided the starting point for several of the lessons I included in the course.
http://paulbourke.net/fractals	Paul Bourke has created hundreds of graphics and collated many photos that illustrate fractals.
www.itsokaytobesmart.com/post/37158097971/infinity-imagined-fractal-river-networks	Striking satellite photography of fractal river networks.
http://www.sosmath.com/matrix/matrix.html	Overview of Matrix Algebra
http://www.mathsisfun.com/algebra/matrix-introduction.html	Subtopics within Matrices (includes questions)
http://ocw.mit.edu/courses/special-programs/sp-268-the-mathematics-in-toys-and-games-spring-2010/	This online program run by MIT Open Courseware is generally too complex for a Stage 5 class, but it guided a lot of the thinking in the "Play: The Mathematics Behind Games" topic.
http://www.youthcarefoundation.org/training.htm	Set Theory exercises
http://www.math-aids.com/Venn_Diagram/	Venn diagram quiz generator
http://www.theguardian.com/science/series/a-short-history-of-equations	A Short History of Equations – a great series of articles posted on the Guardian that explains many interesting mathematical formulae in reasonably simple terms (though they are still quite complicated).
https://www.youtube.com/playlist?list=PLE3376FF44087B17B	An impressive playlist of videos by TED-Ed, mostly animations but also some live presentations (all with very high production values).

4.3 Other resources

The following materials were also used in the preparation and implementation of the course:

- Donald Duck in Mathemagic Land (video)
- Videos by Marcus du Sautoy produced by Teachers.TV
  - Zero to Infinity
  - Lucky Numbers
  - Safety in Numbers
  - Patterns in Nature

5: Appendix

5.1 Extra material

Numerous topics were considered for inclusion in the course, but eventually rejected due to a variety of factors (e.g. insufficient knowledge in the area, uncertainty about how to approach the topic in a classroom context, deemed inappropriate for students with only stage 5 background knowledge). They may or may not be included in future iterations of the course.

- Topology
- Knot theory
- Graph theory
- Computational mathematics (as envisioned in Conrad Wolfram's CBM course, viewable at: www.computerbasedmath.org)
- Formal game theory
- Informatics
- The history and personalities of mathematics

5.2 Remarks for teachers

One of the primary challenges in teaching this course is to help students see the cohesion and overlap between wildly different fields of mathematics. However, XM makes no apology for covering topics that are deliberately excluded from the standard sequence of high school maths programs due to the fact that they do not connect substantially to the other more well-established areas of mathematical study.

A-8. Exploring Mathematics Assessment Outline

| Exploring Mathematics: AT1 (Class Discussion)

1 Overview

Exploring Mathematics emphasises the importance of metacognition (intentional thinking about the learning process). This skill is developed and displayed through the Class Discussion assessment task (AT1).

2 Task Requirements

Reflection posts are written in response to content covered during lessons. These are intended to provide students with the opportunity to think carefully about what has been learned during each lesson and how it relates to existing knowledge, as well as to open a dialogue with peers over mathematical ideas. These can be written by using the following questions as a scaffold:

- What new concepts/skills did I learn?
- How does this relate to things I already know?
- What old ideas have been challenged?
- Was anything surprising? Why?
- Was anything particularly difficult to understand? Why?
- What unanswered questions do I have that enable me to think more deeply about the concepts/skills that were introduced?

These posts are produced by students individually and then logged electronically on the class website. The method for logging these is as follows:

a) Compose a new email to exploringmathematics2015@gmail.com
b) In the subject, write a descriptive title for your post and include your name in brackets. E.g. *Examples of the Golden Ratio in nature (by Chris Martin)*
c) In the body, write your 100-200 words of reflection in response to the prompts given in class (or using the scaffold questions above)
d) Within 15 minutes, your post should appear at www.misterwootube.com/tag/exploremaths

3 Marking Rubric

Since this is an ongoing assessment task, student work will be evaluated at the following three points during the semester:

Friday 6 March	Friday 1 May	Friday 12 June

In addition to work being consistently submitted in a timely fashion, the following guidelines will be used to mark students' work:

Level of competence demonstrated	**Marks**
Demonstrates sophisticated metacognitive understanding of mathematics by: ➤ exhibiting appropriate questioning of and reflection upon relevant ideas ➤ applying and explaining the nature of mathematical thought ➤ presenting coherent discussion with clarity that displays multi-faceted understanding of mathematical concepts ➤ evaluating and discussing the implications of mathematical concepts in broader contexts than the ones presented during lessons	9-10
Demonstrates strong metacognitive understanding of mathematics by: ➤ exhibiting some questioning of and reflection upon relevant ideas ➤ explaining the nature of mathematical thought ➤ presenting discussion that displays multi-faceted understanding of mathematical concepts	7-8
Demonstrates basic metacognitive understanding of mathematics by: ➤ exhibiting some reflection upon relevant ideas ➤ describing mathematical thought in a brief and rudimentary way	3-6
Demonstrates basic understanding of mathematics by: ➤ composing posts related directly or indirectly to the given skills and concepts	1-2
Non-attempt	0

| Exploring Mathematics: AT2 (Artwork)

1 Overview

The opening topics of *Exploring Mathematics* introduce students to the significant connection between beauty and mathematics. Appreciation and investigation of this connection takes places through the creation of a mathematical Artwork (AT2).

2 Task Requirements

Students are to create a two-dimensional artwork that portrays beauty both in a mathematical and non-mathematical context (i.e. someone without a mathematical background ought to be able to appreciate its aesthetic qualities in some measure). They may choose to incorporate one or several of the concepts explicitly introduced in class, such as:

- The Golden Ratio
- Symmetry
- Fractals

Alternatively, students are free to include mathematical ideas that they discover through their own research or experimentation.

The artwork should be a minimum of A3 in size, and must be supplemented by a **1-page rationale** that verbally explains the mathematical concepts or principles that underpin the artwork.

3 Marking Rubric

Students must submit AT2 during or before the scheduled lesson Wednesday 10 September (Week 9, Term 3). The following guidelines will be used to mark students' work (see overleaf):

Level of competence demonstrated	**Marks**
Demonstrates sophisticated understanding and appreciation of beauty in a mathematical context by: ➤ producing an artwork that clearly embodies mathematical principles ➤ creatively designing and composing an original work ➤ clearly explaining a range of relevant mathematical concepts in relation to artwork through written rationale	13-15
Demonstrates strong understanding and appreciation of beauty in a mathematical context by: ➤ producing an artwork that embodies mathematical principles ➤ designing and composing an original or derivative work ➤ describing a range of relevant mathematical concepts in relation to artwork through written rationale	9-12
Demonstrates basic understanding and appreciation of beauty in a mathematical context by: ➤ producing an artwork that vaguely embodies mathematical principles ➤ composing an entirely derivative work ➤ describing a relevant mathematical concept in relation to artwork through written rationale	5-8
Demonstrates some understanding of beauty in a mathematical context by: ➤ producing an artwork that may or may not obviously embody any mathematical principle ➤ composing a simplified or inarticulate written rationale	1-4
Non-attempt	0

| **Exploring Mathematics:** AT3 (Set Theory Quiz)

1 Overview

Set theory is a critically important branch of mathematical logic that concerns the study and language of groups of objects. Many of the skills that are fundamental to understanding sets can be assessed through a short response quiz.

2 Task Requirements

Students are given 40 minutes to complete a quiz that includes the following concepts and skills:

- Set terminology and notation
- Set operations
- Construction and interpretation of Venn and Carroll diagrams

This task will be administered in a normal classroom during a regularly scheduled lesson.

3 Marking Rubric

Students will be assessed on their ability to correctly understand the language of set theory and infer accurate conclusions in given scenarios. Additionally, in some questions, students will be required to demonstrate the conceptual logic beneath their final responses.

| **Exploring Mathematics:** AT4 (Video Composition)

1 Overview

Mathematical ideas are often complicated and multi-faceted, which presents a genuine challenge to both students (trying to learn a concept) and teachers (trying to explain a concept). Though many different strategies have been employed throughout history to communicate mathematics in an intelligible way, the primary medium that has been used by mathematicians has been in the form of written text. It is well-suited to the structure of linear thought, and is easily shared because it is a cheap and accessible format.

In recent years, the rise of various technologies (e.g. the internet, mobile devices, cameras) has meant that *short-form video* is now increasing in popularity and use. Students find it a useful resource (for learning) and teachers find it a powerful tool (for explaining).

2 Task Requirements

In groups of 4-5, students will create a digital video that satisfies the following conditions:

- Consists of an informative presentation about or applying any topic in mathematics related to or an extension of the students' syllabus level, targeted at their peers
- Include both audio and visual components
- Between 90 and 180 seconds long
- Be original

The final video must contain a title, credits, and a Creative Commons BY-NC-ND 3.0 AU license. If any students are physically identifiable in the video clip, guardian permission must be secured and submitted in hardcopy.

3 Marking Rubric

Students must submit AT4 by USB (or a suitable file-sharing service) in two stages:

- Stage 1 (draft): during or before scheduled lesson Wed 22 October (Week 3, Term 4).
- Stage 2 (final product): during or before scheduled lesson Fri 31 October (Week 4, Term 4).

Projects will be assessed on the following criteria:

- Accuracy and quality of mathematics presented
- Innovative approach to presenting mathematics
- Creativity of overall presentation
- Quality of production

After all groups' videos are submitted, the best will be nominated and submitted as the CTHS entry to the *Maths via Digital Media Competition* administered by the University of Wollongong.

Level of competence demonstrated	Marks
Demonstrates sophisticated understanding of mathematics and highly-developed communication skills by: ➤ conveying a difficult mathematical concept/skill in an accurate fashion ➤ showing the concept/skill in an engaging and interesting way ➤ producing a creative and original presentation ➤ utilising the highest possible production values in the final product	13-15
Demonstrates strong understanding of mathematics and reasonable communication skills by: ➤ conveying a mathematical concept/skill in an accurate fashion ➤ showing the concept/skill in an interesting way ➤ producing a creative presentation ➤ utilising substantial production values in the final product	9-12
Demonstrates basic understanding of mathematics and elementary communication skills by: ➤ conveying a mathematical concept/skill in an accurate fashion ➤ producing a creative presentation	5-8
Demonstrates limited understanding of mathematics and some communication skills by: ➤ conveying a mathematical concept/skill ➤ producing a derivative presentation	1-4
Non-attempt	0

| **Exploring Mathematics:** AT5 (Matrices Quiz)

1 Overview

Matrices are one of the most powerful tools in all of mathematics. This is for two reasons. Firstly, these humble grids of numbers are able to represent countless amounts and types of information (such as systems of linear equations and vectors in any number of dimensions). Secondly, their highly structured nature makes them ideally suitable to be handled and manipulated by computers, which enables all the vast processing power of the electronic age to be directed at solving any problem that can be expressed mathematically.

2 Task Requirements

Students are given 30 minutes to complete a quiz that includes the following concepts and skills:

- Interpreting and constructing augmented matrices
- Elementary row operations
- Matrix multiplication
- Inverse of a matrix
- Determinant of a matrix

This task will be administered in a normal classroom during the regularly scheduled lesson on Tuesday 4 November (Week 5). Any students who miss the task at this time will have the opportunity to do it the next day (Wednesday 5 November).

3 Marking Rubric

Students will be assessed on their ability to correctly understand the language of matrices and to accurately manipulate matrices with standard operations and algorithms.

A-9. Osterley High School Year 7 Angles Task

Course:	Stage 4 Mathematics	Year:	7
Topic:	Angles		
Task Name:	'Angles' Research Task		
Date Due:	First Lesson, Week 7		

Task Information

Important idea(s) being explored:	Angles are found in everyday life. Can you identify where they are found? Can you draw angles and measure different types of angles?
Task outline:	You are required to fill in the table template provided for all angles listed below. • Acute angle • Right angle • Obtuse angle • Straight angle • Reflex angle • Revolution • Complementary angles • Supplementary angles • Vertically opposite angles • Adjacent angles
Specific requirements:	• You are to work individually on the research task. • You can type up the table using the template, print it off and draw any diagrams by hand, or you can handwrite onto the table provided. • Label all angles using capital letters. • Draw the diagrams in pencil and ensure that they are large and clear. • Illustrations must be from books, magazines, newspapers or the internet.

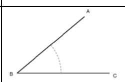
Type of angle	Definition	Diagram (Label the angles)	Illustration of angle found in real life (clearly highlight where the angle is)
Acute angle			
Right angle			

Students may be tested on the following syllabus outcomes: **MA4-18MG** Identifies and uses angle relationships	Use the language, notation and conventions of geometry • Define, label and name points, lines and intervals using capital letters • Label the vertex and arms of an angle with capital letters • Label and name angles using $\angle P$ or $\angle PQR$ notation • Use the common conventions to indicate right angles and equal angles on diagrams. Recognise the geometrical properties of angles at a point • Use the terms 'complementary' and 'supplementary' for angles adding to 90° and 180° respectively, and the associated terms 'complement' and 'supplement' • Use the term 'adjacent angles' to describe a pair of angles with a common arm and common vertex • Identify and name right angles straight angles, angles of complete revolution and vertically opposite angles embedded in diagrams. • Recognise that adjacent angles can form right angles, straight angles and angles of revolution (Communicating, Reasoning)

Marking Information

Marking criteria:	• 1 mark for each correct definition. • 1 mark for each correct diagram; 1 mark for correct labelling • 1 mark for each illustration of the angle in real life; 1 mark for highlighting the angle on the illustration Total marks: 50

Exemplar

Type of angle	Definition (1 mark each)	Diagram (Label the angles) (2 marks each)	Illustration of angle found in real life (clearly highlight where the angle is) (2 marks each)
Acute angle	An acute angle is an angle that is less than 90°		

Year 7 Angles Research Task Name: Class:

Type of angle	Definition (1 mark each)	Diagram (Label the angles) (2 marks each)	Illustration of angle found in real life (clearly highlight where the angle is) (2 marks each)
Acute angle			
Right angle			
Obtuse angle			
Straight angle			
Reflex angle			
Revolution			
Complementary angles			
Supplementary angles			
Vertically opposite angles			
Adjacent angles			

A-10. Osterley High School Year 7 Percentages Task

Assessment Task 3

Course:	Stage 4 Mathematics	Year:	7
Topic:	Fractions, Decimals and Percentages		
Task Name:	**Percentages Task**		
Date Due:	Part 1: First lesson, Week 5, Term 3 Part 2 and 3: First lesson, Week 8, Term 3		

Task Information

Important idea(s) being explored:	Percentages are used in various situations every day. Students will be assessed on their ability to identify these real-life scenarios and operate with percentages in these contexts.
Task outline:	<u>PART 1</u> – **COLLAGE** (*To be completed at home*) **Create an A4 collage** on a separate sheet of paper/cardboard. The collage must have the heading "*Percentages*", and your name and class clearly visible. <u>Specific requirements:</u> • The collage should contain as many examples as possible of **percentages in everyday life.** Cut out examples from newspapers, magazines, brochures and products or print off pictures and advertisements from the internet. You may also include photographs. Each example **must show the context** in which the percentages have been used (**eg** the whole advertisement or an entire quote) • The collage must have **<u>at least six</u>** examples of percentages and must include at least one percentage that **<u>is not</u>** a multiple of 5. **THE COLLAGE IS DUE: _________________________** <u>PART 2</u> – **OPEN-ENDED TASK** *(To be completed in class)* • You will be given some questions to answer using one of the percentages you have used in your collage. These questions will be about ordering, converting and operating with percentages, fractions and decimals. • Calculators will be **allowed**. **DATE OF PART 2: ___________________** <u>PART 3</u> – **LITERACY TASK** *(To be completed in class)* • You will be given a cloze passage to complete using a narrative about percentages. **DATE OF PART 3: ___________________**
Syllabus outcomes:	• Write a fraction in its simplest form • Add and subtract fractions using written and calculator methods • Place fractions and decimals on a number line to compare their relative values • Connect fractions, decimals and percentages and carry out simple

Marking Criteria

Part 1: Collage	• 1 mark for each example of a percentage, in context, in everyday life (total 6 marks) • 1 mark for an A4 sized collage poster • 1 mark for including a title, your name and class • 1 mark for including at least one percentage that is NOT a multiple of 5 • 1 mark for presentation and creativity **Total marks Part 1: 10**
Part 2: Open-ended task	• Marks will be indicated on the task paper • The open-ended task will consist of 3 sections **Total marks Part 2: 20**
Part 3: Literacy task	• One mark for each correct choice of word (total 8 marks) • Two marks for using the passage to answer the problem **Total marks Part 3: 10**

Name :..

YEAR 7 Assessment Task 3

Part 2 and Part 3

Topics: Understanding and computation with Fractions, Decimals and Percentages

General Instructions

- Reading Time- 5 minutes
- Working Time: 20 minutes Part 2; 10 minutes Part 1
- Write using a blue or black pen
- Calculators are permitted

Part 1: Poster (previously submitted)	/10
Part 2: Open-ended task	/20
Part 3: Literacy in percentages	/10
Total	/40

Outcomes Tested

Fractions, Decimals and Percentages

MA4-5NA operates with fractions, decimals and percentages

Working Mathematically

MA4-1WM communicates and connects mathematical ideas using appropriate terminology, diagrams and symbols

MA4-2WM applies appropriate mathematical techniques to solve problems

MA4-3WM recognises and explains mathematical relationships using reasoning

NAME: ______________________ *Year 7 Percentages Part 2*

Part 2: Open-Ended Task (3 sections, 20 marks)

Section 1 (2 marks)

Using your collage, select one of the percentages you have displayed and explain what it has been used for in as much detail as possible.

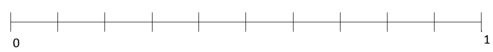
Section 2 (3 questions, 10 marks)

Your teacher has selected **<u>one</u>** of the percentages displayed on your collage. It is written below:

Answer the following questions using the above percentage:

1) (a) Place each of these numbers on the number line provided (***4 marks***)

70% ½ 0.4 0.9



(b) Place your percentage in the correct position on the same number line above (***1 mark***)

2) (a) Convert your percentage into a fraction (express in simplest form) (*1 mark*)

____

(b) Find half of this fraction (*1 mark*)

____

(c) Write down two fractions that add to give your fraction in part **(a)** (*1 mark*)

____

3) (a) Convert your percentage into a decimal (*1 mark*)

____

(b) Calculate: (*1 mark*)

[ ] + 0.65 = ________________

Your percentage

Section 3 (8 marks)

The following numbers have been placed on a number line.

0.03 15% $\frac{1}{3}$ $\frac{1}{2}$ 0.6 $\frac{3}{4}$ $\frac{9}{10}$ 100%

Use all necessary mathematical calculations (show working below) to show that these fractions, decimals and percentages are ordered from smallest to largest.

NAME: ______________________ *Year 7 Percentages Part 3*

Part 3: Literacy in percentages (10 marks)

Complete the following cloze passage by inserting the most appropriate word from the word bank below.

Profit	Loss	Percent	Multiply
Divide	Calculate	Thirty-five	Percentage
Fraction	Three-quarters	Seventy-five	Subtract
Add	Twenty-five	Increase	Decimal
Decrease	Sixty-five	Fifty	Out of

Narrative (8 marks)

One morning, Ms Pearn read a newspaper article that said approximately three-quarters of Australian children between the ages of twelve and fourteen own a mobile phone.

“That’s very interesting,” Ms Pearn thought out loud, “I wonder how many Year 7 students at NHSPA own a mobile phone.”

Mr Atkinson overheard her and replied, “We could estimate that, couldn’t we?”

“That’s true! Three-quarters is ___________________ percent. If we knew how many Year 7 students there were, we could easily ____________________ a reasonable estimate!”

“That’s right, we would only need to _________________ the percentage with the number of students we have. You know, we could convert the percentage to a ________________ or a ___________________ before we did any calculations.”

Ms Pearn nodded in agreement and continued reading, “By the time they are 15, that number surges up to 90 _________________!”

“Wow! That is a significant percentage ____________________ in just over a year or two,” replied Mr Atkinson.

“These statistics must be fantastic for mobile phone companies. They must make a serious ______________________ from mobile phone usage in Australia!”.

Cloze problem (2 marks)

If there are 180 students in Year 7 (who are between the ages of 12 and 14 years old), use the information in the narrative to calculate an estimate of the number of students who would own a mobile phone. Show all working.

____

____

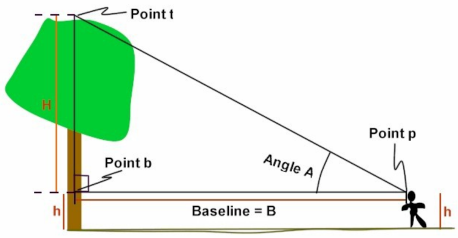
A-11. Osterley High School Year 9 Trigonometry

Year 9 - Mathematics

Trigonometry - Research Task

Due Date: 8 Aug 2017

Trigonometry is a branch of Mathematics that uses properties of triangles to calculate various lengths and angles.



Part 1 - Trigonometry Investigation

a) **Build your own clinometer.** This must be submitted with your research task. **(2 Marks)**

A clinometer is a tool used to measure the angle of elevation, or angle from the ground in a right-angled triangle. You can use a clinometer to measure the height of objects you cannot practically measure.

Follow the directions below to create your own clinometer.

You will need:

- A protractor with a small hole on the centre spot or print out of a protractor glued onto thick cardboard
- 20 cm of string or strong cotton
- A weight --- such as a metal nut, paper clips or a small piece of clay
- Glue and scissors
- A plastic drinking straw
- Clear adhesive/ sticky tape

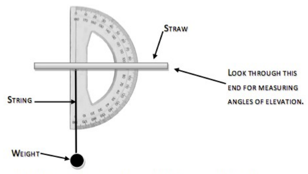


Figure 1: *The diagram shows what the assembled clinometer will look like when horizontal. The angle of elevation will be 0°.*

Tip: Research clinometers to gain a greater understanding of what this device looks like and how it works.

Directions:

- With a thumbtack, nail or other sharp implement, poke a hole through the centre crossbar of the protractor.
- Push the string through the hole and tie a large knot on the other side so it won't pull through
- Tie the weight to the other end of the string.
- Tape the straw so that it lies over the 90° marking on the protractor. Place it on the same side of the protractor as the knot, to allow the weighted string to swing freely.

b) **Use the clinometer to measure the angle of elevation of a tree, a building and one other object. (21 marks)**

You will need two people to use the clinometer. One person, to look through the straw and site the top of an object and one person, to read the angle (in degrees) that the string makes with the protractor.
****Note:** This is still an individual task and all of the work submitted must be entirely your own.

- Find a tall tree, a tall building and 1 other object taller than yourself that you can reach the top of without standing on anything.
- Look through the straw and find the top of the tree.
- Ask your friend to read the angle being recorded on the clinometer. This is read where the string or cotton is touching the protractor.
- Measure the distance between where you are standing and the base of the tree.
- Measure the distance from your eyes to the ground (this is where your partner is indispensible!)

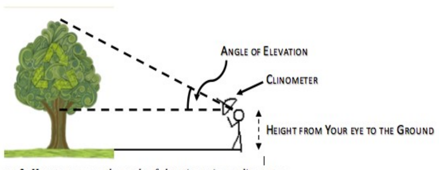


Figure 2: *How to measure the angle of elevation using a clinometer*

c) **Calculating the height of each object**

(i) Draw a diagram for each of the three objects, including the angle of elevation, your distance from the object, and your eye height.

(ii) Calculate the height of each object (tree, tall building and object), showing all working. Working should include the following:

- Correct trigonometric ratio
- Correct side length of triangle
- Addition of eye height for total height of object
- Correct units and answer to 1 decimal place

d) **Create a visual presentation (7 marks)**

Using a comic strip creation website to create a comic strip, or an alternative computer based pictorial method, to **explain the process** you went through to **measure the height of the tree.** Websites to try include

- http://stripgenerator.com/strip/create
- http://www.toondoo.com/
- www.pikistrips.com
- http://www.makebeliefscomix.com/Comix/

Alternative computer based methods include *Keynote*, iMovie or a poster (using printed photos). No hand drawn comics! The comic strip must have a **minimum** of 5 slides / panels.

Part 2 – Trigonometry in Action

Some of the early ways of measuring the height of tall structures are still in use today. They require very little equipment and can be used out in forests where special equipment is hard to come by. We are going to look at four methods. You will then compare your results to discover if the answers you get are close - they should be. After all, the tree does not change its height because you change your measurement method! You might be surprised just how accurate you can be.

1) **Native American Method**

Native Americans had a very interesting and unusual way of seeing how high a tree was. They would bend over and look through their legs!

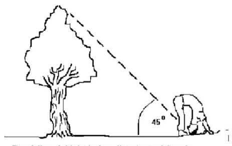


Figure 3: How to find the height of a tree Native American Indian style.

They would walk far enough from the tree to a find a place where they were just able to see the top of the tree (from their upside down position). The distance from this place to the base of the tree was approximately the height of the tree. Does it work? Actually it does and the reason is rather simple. For a normal, fit and healthy adult (one who can bend over in such a way), the angle that is formed as they look through their legs is approximately 45 degrees. The angle between the tree trunk and the ground is fairly close to 90 degrees and, using what you know about the angles and sides of a triangle you can work out the height of the tree. The height of the tree and the distance from the tree to the person is about equal. Therefore, knowing the distance to the tree gives you a good idea about the height of the tree. It certainly saves having to carry heavy surveying equipment around.

Questions: (4 marks)

(a) Draw a diagram similar to Figure 3, showing how you used this method, labelling all measurements (all three angles, your distance from the tree, the height of the tree).

(b) What sort of triangle did you draw?

(c) Why does this method work in finding the height of the tree? (*Hint:* what are the properties of the triangle?)

2) **Lumberjack Method**

Lumberjacks /loggers are people who cut down trees. They learned a great deal from people who lived in forests for generations, like the Native Americans. They might be cutting down trees that are over a certain height and it is important that they have an easy way to estimate which of the trees around them are to be cut. You can try and estimate the height of a tree or a building using their method.

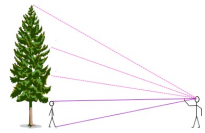


***Figure 4:** How to find the height of a tree Tree Logger method.*

You need a partner (this can be anybody who is available to assist you while you conduct the measurements) who stands at the base of the tree. Move a distance away from the tree then, holding your pencil at arms' length, between your thumb and forefinger so that it brackets the height of your partner (the top and bottom of the pencil coincide with the top of the head and the bottom of the feet of your partner). Now, use this length to step out the height of the tree in "pencil lengths". You can now measure the height of your partner and multiply this by the number of pencils high the tree is. This is worth doing several times from different distances and working out an average to improve the accuracy.

This is quite easy, once you have the knack. Describing the method makes it sound way more complicated than it is. After a couple of tries, you'll be able to apply for a lumberjack's job!

Questions: (4 marks)

a) What was the height of your partner (to the nearest centimetre)?

b) How many "pencil lengths" did you estimate to fit into the height of the tree?

c) Show your calculation for how you worked out the height of the tree. Give your answer in metres to 1 decimal place.

3) **Shadows Method**

Now try a third method. Don't forget to be comparing the sizes that you are getting for the tree height to see how they match up.
You will need a partner again, and another thing that you will need is a sunny day. You might have to pick your time for this experiment.

We'll call this method Measuring Shadows. Wait until the tree casts a shadow then measure the length of the shadow. Stand next to the tree and have a friend or parent measure your shadow. Be sure to do it as soon as you can after you measure the tree shadow, since shadows cast by the sun continually change as the earth rotates. Measure your height to find out how tall you are. Now for the good part - get those calculators out! You will need the 3 measurements:

- the length of the tree's shadow
- the length of your shadow
- your height

Divide the length of the tree's shadow by the length of your shadow. Then multiply the answer by your height. This will tell you how tall the tree is!

(Tree's Shadow / Your Shadow) x Your Height = Tree's Height

Questions: (4 marks)

a) What was the length of the tree's shadow?

b) What was the length of your shadow?

c) What was your measured height?

d) Calculate the tree's height, showing your working. Give your answer in metres to 2 decimal places.

4) **Clinometer Method**

Use your clinometer created in Task 1 to calculate the angle of elevation and height of the tree. Remember your working should include the following:

- Correct trigonometric ratio
- Correct side length of triangle
- Addition of eye height for total height of object
- Correct units and answer to 1 decimal place

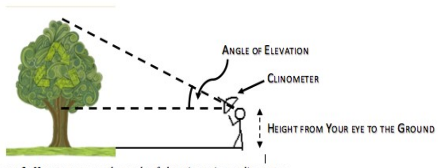


***Figure 2:** How to measure the angle of elevation using a clinometer*

5) **Summary and comparison of results** (4 marks)

a) Present a summary of your results in a table.

b) Which of the four methods (Clinometer, Native American, Lumberjack or Measuring Shadows) in this task would you prefer to use, and why?

END OF TASK

** Include a cover sheet
** Ensure you name is written on each page.
** Include the marking criteria with your research task
** Students will present their visual presentation to both classes on the due date.

Year 9 Stage 5:3 Trigonometry Research Task Marking Criteria

Name (s) ____

TASK 1 – Trigonometry Investigation Total / 30 marks

a) Create a clinometer (2 marks)

* Clinometer accurately constructed with no alignment issues allowing accurate measurements	2
* Basic clinometer is produced with minor flaws in alignment	1
* No clinometer produced or very imprecise construction	0

b) & c) Tree - Measurements / Diagrams / Calculations (7 marks)

b) Angle of elevation of a tree measured * No angle of elevation given or unrealistic measurement given	1 0
c) (i) Ruler used to draw neat and labelled diagram showing the angle of elevation, your distance from the object and your eye height (including dimensions) * Neat diagram drawn showing some labelling and /or measurements. * Poorly drawn diagram with limited labelling/ measurements or no diagram included.	2 1 0
c)(ii) Calculate the height of the tree showing all working. Working should include the following: • Correct trigonometric ratio (1 mark each object) • Correct side length of triangle (1 mark each object) • Addition of eye height for total height of object (1 mark each object) • Correct units and answer to 1 decimal place (1 mark each solution object)	 1 0 1 0 1 0 1 0

b) & c) Tall building- Measurements / Diagrams / Calculations

b) Angle of elevation of a tall building measured * No angle of elevation given	1 0
c) (i) Ruler used to draw neat and labelled diagram showing the angle of elevation, your distance from the object and your eye height (including dimensions) * Neat diagram drawn showing some labelling and /or measurements. * Poorly drawn diagram with limited labelling/ measurements or no diagram included.	2 1 0
c)(ii)Calculate the height of the tall building showing all working. Working should include the following: • Correct trigonometric ratio (1 mark each object) • Correct side length of triangle (1 mark each object) • Addition of eye height for total height of object (1 mark	 1 0 1 0

b) & c) Object - Measurements / Diagrams / Calculations

b) Angle of elevation of object measured * No angle of elevation given	1 0
c) (i) Ruler used to draw neat and labelled diagram showing the angle of elevation, your distance from the object and your eye height (including dimensions) * Neat diagram drawn showing some labelling and /or measurements. * Poorly drawn diagram with limited labelling/ measurements or no diagram included.	2 1 0
c)(ii)Calculate the height of the object showing all working. Working should include the following: • Correct trigonometric ratio (1 mark each object) • Correct side length of triangle (1 mark each object) • Addition of eye height for total height of object (1 mark each object) • Correct units and answer to 1 decimal place (1 mark each solution object)	 1 0 1 0 1 0 1 0

d) Visual presentation (7 marks)

* Use of comic-strip creation or alternative compute-based method	1 0
* 5 or more panels / slides	1 0
* Appropriate use of mathematical language / notation	1 0
*Correct spelling	1 0
*Visual effectiveness	1 0
* Logical sequencing and clear explanation of process	2 1 0

Part 2 - Trigonometry in Action Total / 20 marks

1) Trigonometry – the Native American Way (4 marks)

a)Ruler used to draw neat and labelled diagram (similar to Figure 3) showing how you used this measurement, labelling all measurements (all three angles, your distance from the tree, the height of the tree) * Neat diagram drawn showing some labelling and /or measurements * Poorly drawn diagram with limited labelling/ measurements or no diagram included.	2 1 0
(b) What sort of triangle did you draw?	1 0
(c) Why does this method work in finding the height of the tree? (Hint: what are the properties of the triangle?)	1 0

2) Trigonometry – the Lumberjack Way (4 marks)

a) Partner's height to the nearest centimetre	1 0
b) Stated "pencil lengths" estimated to fit into the height of the tree?	1 0
d) Height of the tree calculated (working included). Answer in metres to 1 decimal place. *Height of tree provided – limited working- not rounded to one decimal place. * Answer only / not necessarily rounded – no answer	2 1 0

3) Trigonometry – the Shadow Way (4 marks)

a) Length of the tree's shadow	1 0
b) Length of your shadow	1 0
c) Students measured height?	1 0
e) Tree's height (working included). Answer in metres to 2 decimal places. * marks not deducted for incorrect rounding	1 0

4) Trigonometry - Using the clinometer (4 marks)

Correct trigonometric ratio	1 0
Correct side length of triangle	1 0
Addition of eye height for total height of object	1 0
Correct units and answer to 1 decimal place	1 0

5) Summary of results (4 marks)

a) Tabulated summary of results from four methods.	1 0
b) Stated prefered method (Clinometer, Native American Indian, Lumberjack or Measuring Shadows)	1 0
b) Reasons provided * Extensive valid reasoning * Limited or unsupported reasoning * No genuine attempt to provide valid reasons	 2 1 0

A-12. Osterley High School Year 11 General 2 Task

Sample of 16 pages from a total of 61 pages.

General Mathematics Preliminary Course Mathematics and Driving

General Mathematics Preliminary
Focus Study: Driving

Name: ______________________________

Class Teacher: ______________________

This task has been split up into Checkpoints to assist you in completing all components

Date for Checkpoint 1	Term 1, Week 5	24th February 2017
Date for Checkpoint 2	Term 1, Week 7	10th March 2017
Date for Checkpoint 3	Term 1, Week 9	24th March 2017

Submission of Assignments:
All checkpoints are to be submitted in class on the due date.

Booklets:
This assignment has been prepared as a booklet for your convenience. You will be issued one booklet only.

You may decide to submit your assessment task in a folder or as each part.

General Mathematics Preliminary Course Mathematics and Driving

Topic: Driving

Content to be assessed:

FSDr1 Cost of purchase and insurance

FSDr2 Running costs and depreciation

FSDr3 Safety

Outcomes to be addressed:

MGP – 1 uses mathematics and statistics to compare alternative solutions to contextual problems
MGP – 2 represents information in symbolic graphical and tabular form
MGP – 3 represents the relationships between changing quantities in algebraic and graphical form
MGP – 5 demonstrates awareness of issues in practical measurement, including accuracy and choice of relevant units
MGP – 6 models financial situations relevant to the student's current life using appropriate tools
MGP – 7 determine an appropriate form of organisation ad representation of collected data
MGP – 8 performs simple calculations in relation to the likelihood of familiar events
MGP – 9 uses appropriate technology to organise information from a limited range of practical and everyday contexts
MGP – 10 justifies a response to a given problem using appropriate mathematical terminology

General Mathematics Preliminary Course Mathematics and Driving

Assignment Overview

Checkpoint	Deliverables	Marks
Checkpoint 1 Getting a new car 24th February 2017	○ Vocabulary worksheet ○ Licence details ○ Car details ○ Registration details ○ Loan details	76
Checkpoint 2 Cost of running your car 10th March 2017	○ Budget for running your car ○ Insurance ○ Depreciation on car	90
Checkpoint 3 Responsibilities of Driving 24th March 2017	○ Stopping distances ○ Blood Alcohol Concentration ○ Motor vehicle accidents	102
	Total	268

General Mathematics Preliminary Course Mathematics and Driving

Checkpoint 1 Overview

You have decided to buy a car and need to make a choice of the most suitable car for you. You limit yourself to $20 000 for this vehicle. In this part of the assignment you will research 2 different cars and their features. You may use the sites suggested below, or find your own. Please show screenshots of your research.

Checkpoint 1 Due: 24th February 2017

☐ #1. Vocabulary worksheet

☐ #2. What types of licences are available in NSW? What do you need to do to get one and what are your responsibilities for each type?
http://www.rta.nsw.gov.au/licensing/downloads/licenclassindex_dl1.html
http://www.rta.nsw.gov.au/licensing/licence_under18s.html

☐ #3. Research and choose to purchase TWO of the following cars or one you find yourself
*Kia Rio * Honda Civic * Toyota Yaris * Mazda 3

http://www.carsguide.com.au/
http://carsales.com.au/used/new-south-wales/
http://www.gumtree.com.au/s-cars-vans-utes/sydney/
http://www.tradingpost.com.au/Automotive/Used-Cars/

☐ #4. What is the stamp duty and transfer costs for the purchase of this vehicle?
http://www.rta.nsw.gov.au/registration/regorenewal/index.html

☐ #5. Loan
In order to buy the vehicle you will need finance. There is an **attached loan table**. Calculate the monthly repayments for a 12% loan. Assume the loan term is 5 years. Include fees for this loan.
Loan table

☐ #6 What will the car repayments cost you each month if you have a 10% deposit (using loan B)?

#1. Vocabulary Worksheet

In relation to your maths assignment on driving, write a definition for each of following terms.

1	Blood Alcohol Concentration	
2	Blue Slip	
3	Braking Distance	
4	Comprehensive Third Party Insurance	
5	Depreciation	
6	Fuel Consumption	
7	Fully Comprehensive Insurance	
8	Green Slip	
9	Notice of Disposal	
10	On Road Costs	
11	Pink Slip	
12	Reaction Time	
13	Reducing Balance Loan	
14	REVS check	
15	Salvage Value	
16	Speed	
17	Stamp Duty	
18	Stopping Distance	
19	Third Party Property Damage Insurance	
20	Transfer of Registration	

#2. Can I See Your Licence Please?

In NSW, there are different classes of licences. Give an overview of the different types of ***car*** licences, how to qualify for them, their cost and the restrictions of each type. (You may wish to present this in table format)

<table>
<tr><th colspan="4">Checkpoint One Mark Sheet</th></tr>
<tr><th rowspan="2">#</th><th rowspan="2">Title</th><th colspan="2">Marks</th></tr>
<tr><th>Your mark</th><th>Possible marks</th></tr>
<tr><td>Cover</td><td>Name, Teacher's Name</td><td></td><td>2</td></tr>
<tr><td>1</td><td>Vocabulary Worksheet</td><td></td><td>20</td></tr>
<tr><td>2</td><td>Can I see your Licence please?
<table>
<tr><th></th><th>Name</th><th>How to qualify</th><th>Cost</th><th>Restrictions</th></tr>
<tr><td>Car Ls</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Car P1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Car P2</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Car full</td><td></td><td></td><td></td><td></td></tr>
</table></td><td></td><td>16</td></tr>
<tr><td>3</td><td>Pick a car, any car…..
<table>
<tr><th>Organised</th><th>Rio</th><th>Civic</th><th>Yaris</th><th>Mazda</th><th>Student</th></tr>
<tr><td>Price</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Picture</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Model</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Auto/ manual</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Eng Size</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Fuel capacity</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Fuel consump</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tyres</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Safety</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Features</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Evidence</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>
And the winner is…..
<table>
<tr><td>Choice made (1)</td><td>Justification (3)</td></tr>
</table></td><td></td><td>26</td></tr>
<tr><td>4</td><td>On the road again…………
<table>
<tr><td>Registration</td><td>Stamp Duty</td></tr>
<tr><td>Transfer</td><td>Total</td></tr>
</table></td><td></td><td>4</td></tr>
<tr><td>5</td><td>Loan</td><td></td><td>6</td></tr>
<tr><td>6</td><td>But Wait</td><td></td><td>6</td></tr>
<tr><td colspan="2">Total</td><td></td><td>80</td></tr>
</table>

Checkpoint 2 Overview

So you have a licence, the car is picked out and you have sorted the loan but the bills just keep coming…In this section we look at other costs associated with having a car.

☐ #7. A condition of a loan is to have comprehensive insurance with you are the primary driver. Shop around to find the best quote. Provide evidence of these enquires (at least 2).
http:///www.gio.com.au/car-insurance/car-quote-terms
http://www.nrma.com.au/car-insurance/car-insurance-quotes
http://www.commbank.com.au/personal/insurance/apply-online.html
http://www.budgetdirect.com.au/car-insurance/index.html

☐ #8. What will this car cost to own and run for 2 years? You need to include the cost of registration (including CTP green slip), comprehensive insurance, 3 services, driver's licence (assume you have one year on your red P's and one on your green p's which you get first time), one new set of tyres and fuel for 40,000kms (20 000km / year) and loan repayments.You may wish to use a spreadsheet/worksheet to show this information clearly.
Note: If your car is more than 5 years old it will also need a pink slip.
Extension task: You may choose to further develop your costing by considering special services such as air conditioning re-gassing, etc.

☐ #9. How much would you need to budget each week to run this car?

☐ #10. Construct a straight line depreciation graph and declining balance depreciation graph for your car on the same set of axes, given the vehicle depreciates by $3,000 or 20% per annum.

Time	Value using straight line depreciation at $3,000 p.a.	Value using declining balance depreciation at 20%p.a.
After 1 Year		
After 2 years		
After 3 years		
After 4 years		
After 5 years		

#10. Is it worth it?

Construct a straight line depreciation graph and declining balance depreciation graph for your car on the same set of axes, given the vehicle depreciates by $3,000 or 20% per annum.

Time	Value using straight line depreciation at $3,000 p.a.	Value using declining balance depreciation at 20%p.a.
After 1 Year		
After 2 years		
After 3 years		
After 4 years		
After 5 years		

Working out:..

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Checkpoint Two Mark Sheet

#	Title			Marks: Your mark	Marks: Possible marks
7	**Just In Case**				24
		1st Quote	2nd Quote		
	Insurance Company's Name				
	Student as driver				
	Car Details same as #3				
	Post Code relevant				
	Garaging details				
	Evidence of research				
8	**Money, Money, Money………..**				26
		1St Year	2nd Year		
	Registration				
	Comprehensive Insurance				
	3 Services	3 Services:			
	P1 Driver's Licence				
	P2 Driver's Licence				
	Tyres				
	Fuel (20000km/year x 2 years) 0r 40000km	Working out	Answer		
	Loan				
	Total for 2 years				
9	**So what will it cost?** One mark for working out, one mark for answer				4
10	**Is it worth it?**				36
		Table 1	Table 2		
	Start Price				
	Working Out				
	5 Years				
	Final Price				
		Graph 1	Graph 2		
	Title				
	Labels				
	Scale				
	Plotted points				
	Trend apparent				
			Total		90

Checkpoint 3 Overview

In this checkpoint you must complete worksheets for issues that affect driving.
These are:

- ☐ #11. Stopping distances
- ☐ #12. Blood Alcohol Concentration
- ☐ #13. Motor vehicle accidents

Suggested resource: http://lrrpublic.cli.det.nsw.edu.au/lrrSecure/Sites/LRRView/6441/#tabs-2

Stopping Distances

The stopping distance of a car is a critical factor when driving. Accidents are often caused when drivers underestimate what they consider to be a safe distance to leave between vehicles. There are two main factors influencing the stopping distance of a vehicle; The react Ion time of the driver and the braking distance of the vehicle.
The reaction time of a driver can be influenced by tiredness, alcohol and distractions. The braking distance can be affected by speed, road conditions, weather and poor car condition.

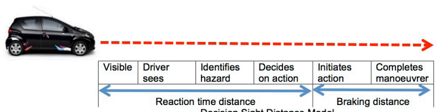
Stopping distance = reaction time distance + braking distance

When driving behind another vehicle, you are always told to leave at least a 3 second gap. Many drivers do not follow these guidelines, believing they would be able to stop in time if the car in front were to brake suddenly. However the reaction time of a driver can be anywhere from 1 to 4 seconds, and the braking distance varies significantly.

Consider travelling at 90 km/h, sitting 40m behind another vehicle. If the car in front of you brakes, the driver of that vehicle has already reacted to something in front of them and has begun to slow down. In the 2 seconds it takes you to react to the situation and apply the brakes you will have already travelled 50m. Assuming a braking distance of 35m;

Stopping distance = 50 + 35
= 85 m

So in the time taken for you to stop you have already travelled 85m, quite possibly colliding with the car in front.



Decision Sight Distance Model

Example 1:
Calculate Brodie's stopping distance if he takes 22m to react and 50m to stop at a set of traffic lights.

Solution:
Stopping distance = reaction time distance + braking distance
= 22 + 50
= 72m

General Mathematics Preliminary Course Mathematics and Driving

Returning your BAC to zero

There are many misconceptions about returning your BAC to zero quickly. Some people believe drinking coffee, having a shower or eating a large meal will help the alcohol leave your body faster. However these methods do not work. A small amount of alcohol leaves your body through sweat and urine, but the majority of it is broken down by your liver. A healthy liver is able to break down less than one standard drink per hour, so if your liver is damaged in any way, it will take even longer.
The only way to ensure you have a BAC of zero before driving is to wait. Drivers on their provisional plates are often booked for drink driving the morning after going out as there is still a significant amount of alcohol in their blood stream.

Consider the following:
Claire (52kg) is on her provisional licence and decides to go out for a friend's 18^{th} and consumes 6 mixed drinks between 7pm and 12am. Each mixed drink is equivalent to 1.5 standard drinks. Claire is worried about driving to work at 6am and thinks she might still have alcohol in her system then. Is she right?

Solution:
Step 1: Calculate Claire's BAC at 12am when she stops drinking.
N = number of drinks = 6 x 1.5 = 9 standard drinks
H = hours of drinking = 5
M = mass = 52kg

$BAC_{Claire} = \frac{10N-7.5\,H}{5.5\,M}$

$= \frac{10\times9-7.5\times5}{5.5\times52}$

$= 0.184$

So after 5 hours drinking, Claire is over the legal limit for a full licenced driver, let alone a P-Plater!

Step 2: Claire needs to drive to work at 6am, will she be over the limit by then?
By 6am, 11 hours will have passed since Claire started drinking.

$BAC = \frac{10N-7.5\,H}{5.5\,M}$

$= \frac{10\times9-7.5\times11}{5.5\times52}$

$= 0.026$

So while Claire is closer to zero, it is still not safe for her to drive.

General Mathematics Preliminary Course Mathematics and Driving

Calculating an estimate for a zero BAC

Using the example above, we have seen that even after sleeping, Claire's BAC is still too high.

To work out an estimate for how long it will take for your BAC to return to zero, we use the same formula, but instead we set the BAC to 0, and solve for the H (the number of hours of drinking)

$$BAC_{Female} = \frac{10N-7.5\,H}{5.5\,M}$$

$$0 = \frac{10N-7.5\,H}{5.5\,M}$$

$$0 = 10N - 7.5H$$

$$7.5H = 10N$$

$$H = \frac{10N}{7.5}$$

Using Claire's details from the previous page to get an estimate for how long she must wait to have a zero BAC:

$$H = \frac{10\times9}{7.5}$$

$$H = 12$$

This tells us that Claire needs to wait for approximately 12 hours from when she started drinking to safely drive home. So since Claire started drinking at 7pm the evening before, she is unable to drive until 7am in the morning at the earliest (remember this formula is an approximation only).

General Mathematics Preliminary Course Mathematics and Driving

Checkpoint Three Mark Sheet

#	Title	Marks: Your mark	Marks: Possible marks
12	**Stopping Distances** 		31
13	**Blood Alcohol Concentration** 		42
14	**Motor Vehicle Accidents** 		34
	Total		107

Comments from the marker:

General Mathematics Preliminary Course Mathematics and Driving

Your Say…….

What did you think about this assignment? Were the questions relevant, too hard, too long,……………??

What issues did you experience completing this assignment?

What did you learn be completing this assignment?

If you did it again, what would you change?

Was the booklet a good idea?

Did you like getting the whole assignment at the start? Did this make a difference to your planning to complete the whole task?

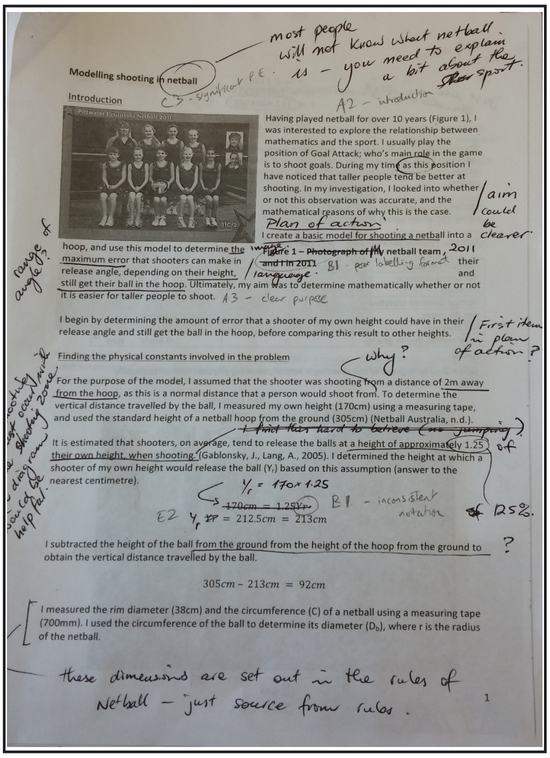
Do you like the Checkpoints?

Other comments?

Name:

A-13. IB Mathematics Standard Level Task: Draft

Sample of 4 pages from Philip's student's IB task draft, with Philip's comments.



Modelling shooting in netball

Introduction

Having played netball for over 10 years (Figure 1), I was interested to explore the relationship between mathematics and the sport. I usually play the position of Goal Attack; who's main role in the game is to shoot goals. During my time as this position I have noticed that taller people tend be better at shooting. In my investigation, I looked into whether or not this observation was accurate, and the mathematical reasons of why this is the case.

Figure 1 – Photograph of my netball team, and I in 2011

I create a basic model for shooting a netball into a hoop, and use this model to determine the maximum error that shooters can make in their release angle, depending on their height, and still get their ball in the hoop. Ultimately, my aim was to determine mathematically whether or not it is easier for taller people to shoot.

I begin by determining the amount of error that a shooter of my own height could have in their release angle and still get the ball in the hoop, before comparing this result to other heights.

Finding the physical constants involved in the problem

For the purpose of the model, I assumed that the shooter was shooting from a distance of 2m away from the hoop, as this is a normal distance that a person would shoot from. To determine the vertical distance travelled by the ball, I measured my own height (170cm) using a measuring tape, and used the standard height of a netball hoop from the ground (305cm) (Netball Australia, n.d.).

It is estimated that shooters, on average, tend to release the balls at a height of approximately 1.25 their own height, when shooting (Gablonsky, J., Lang, A., 2005). I determined the height at which a shooter of my own height would release the ball (Y_r) based on this assumption (answer to the nearest centimetre).

$170cm \times 1.25$

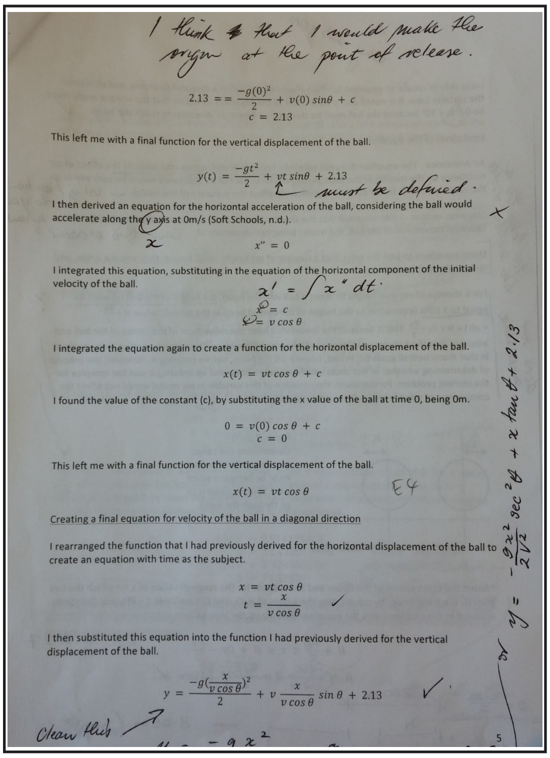
$Y_r = 212.5cm = 213cm$

I subtracted the height of the ball from the ground from the height of the hoop from the ground to obtain the vertical distance travelled by the ball.

$305cm - 213cm = 92cm$

I measured the rim diameter (38cm) and the circumference (C) of a netball using a measuring tape (700mm). I used the circumference of the ball to determine its diameter (D_b), where r is the radius of the netball.

1



$2.13 = -\frac{g(0)^2}{2} + v(0)\sin\theta + c$

$c = 2.13$

This left me with a final function for the vertical displacement of the ball.

$y(t) = \frac{-gt^2}{2} + vt\sin\theta + 2.13$

I then derived an equation for the horizontal acceleration of the ball, considering the ball would accelerate along the y axis at 0m/s (Soft Schools, n.d.).

$x'' = 0$

I integrated this equation, substituting in the equation of the horizontal component of the initial velocity of the ball.

$x' = c$

$x' = v\cos\theta$

I integrated the equation again to create a function for the horizontal displacement of the ball.

$x(t) = vt\cos\theta + c$

I found the value of the constant (c), by substituting the x value of the ball at time 0, being 0m.

$0 = v(0)\cos\theta + c$

$c = 0$

This left me with a final function for the vertical displacement of the ball.

$x(t) = vt\cos\theta$

Creating a final equation for velocity of the ball in a diagonal direction

I rearranged the function that I had previously derived for the horizontal displacement of the ball to create an equation with time as the subject.

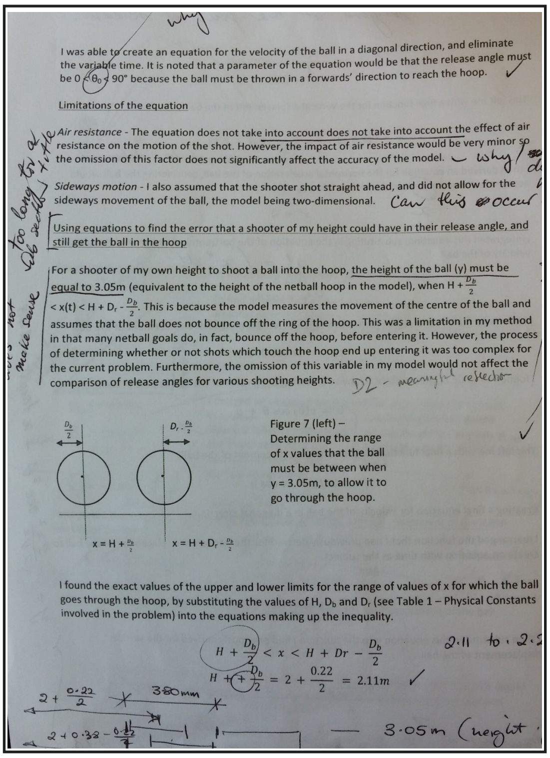
$x = vt\cos\theta$

$t = \frac{x}{v\cos\theta}$

I then substituted this equation into the function I had previously derived for the vertical displacement of the ball.

$y = \frac{-g(\frac{x}{v\cos\theta})^2}{2} + v\frac{x}{v\cos\theta}\sin\theta + 2.13$

5



I was able to create an equation for the velocity of the ball in a diagonal direction, and eliminate the variable time. It is noted that a parameter of the equation would be that the release angle must be $0 < \theta_0 < 90°$ because the ball must be thrown in a forwards' direction to reach the hoop.

Limitations of the equation

Air resistance - The equation does not take into account does not take into account the effect of air resistance on the motion of the shot. However, the impact of air resistance would be very minor so the omission of this factor does not significantly affect the accuracy of the model.

Sideways motion - I also assumed that the shooter shot straight ahead, and did not allow for the sideways movement of the ball, the model being two-dimensional.

Using equations to find the error that a shooter of my height could have in their release angle, and still get the ball in the hoop

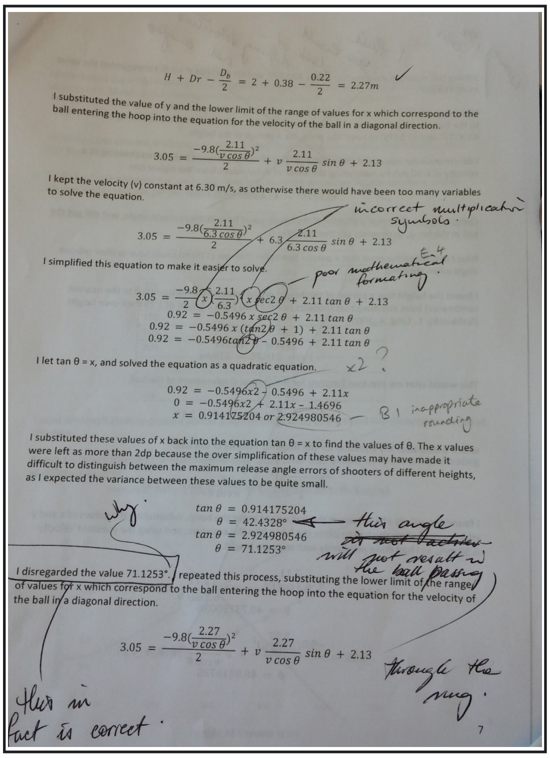
For a shooter of my own height to shoot a ball into the hoop, the height of the ball (y) must be equal to 3.05m (equivalent to the height of the netball hoop in the model), when $H + \frac{D_b}{2} < x(t) < H + D_r - \frac{D_b}{2}$. This is because the model measures the movement of the centre of the ball and assumes that the ball does not bounce off the ring of the hoop. This was a limitation in my method in that many netball goals do, in fact, bounce off the hoop, before entering it. However, the process of determining whether or not shots which touch the hoop end up entering it was too complex for the current problem. Furthermore, the omission of this variable in my model would not affect the comparison of release angles for various shooting heights.

Figure 7 (left) – Determining the range of x values that the ball must be between when y = 3.05m, to allow it to go through the hoop.

I found the exact values of the upper and lower limits for the range of values of x for which the ball goes through the hoop, by substituting the values of H, D_b and D_r (see Table 1 – Physical Constants involved in the problem) into the equations making up the inequality.

$H + \frac{D_b}{2} < x < H + Dr - \frac{D_b}{2}$

$H + \frac{D_b}{2} = 2 + \frac{0.22}{2} = 2.11m$



$H + Dr - \frac{D_b}{2} = 2 + 0.38 - \frac{0.22}{2} = 2.27m$

I substituted the value of y and the lower limit of the range of values for x which correspond to the ball entering the hoop into the equation for the velocity of the ball in a diagonal direction.

$3.05 = \frac{-9.8(\frac{2.11}{v\cos\theta})^2}{2} + v\frac{2.11}{v\cos\theta}\sin\theta + 2.13$

I kept the velocity (v) constant at 6.30 m/s, as otherwise there would have been too many variables to solve the equation.

$3.05 = \frac{-9.8(\frac{2.11}{6.3\cos\theta})^2}{2} + 6.3\frac{2.11}{6.3\cos\theta}\sin\theta + 2.13$

I simplified this equation to make it easier to solve.

$0.92 = -0.5496\,x\sec2\theta + 2.11\tan\theta$

$0.92 = -0.5496\,x(\tan2\theta + 1) + 2.11\tan\theta$

$0.92 = -0.5496\tan2\theta - 0.5496 + 2.11\tan\theta$

I let tan θ = x, and solved the equation as a quadratic equation.

$0.92 = -0.5496x2 - 0.5496 + 2.11x$

$0 = -0.5496x2 + 2.11x - 1.4696$

$x = 0.914175204$ or 2.924980546

I substituted these values of x back into the equation tan θ = x to find the values of θ. The x values were left as more than 2dp because the over simplification of these values may have made it difficult to distinguish between the maximum release angle errors of shooters of different heights, as I expected the variance between these values to be quite small.

$\tan\theta = 0.914175204$

$\theta = 42.4328°$

$\tan\theta = 2.924980546$

$\theta = 71.1253°$

I disregarded the value 71.1253°, repeated this process, substituting the lower limit of the range of values for x which correspond to the ball entering the hoop into the equation for the velocity of the ball in a diagonal direction.

$3.05 = \frac{-9.8(\frac{2.27}{v\cos\theta})^2}{2} + v\frac{2.27}{v\cos\theta}\sin\theta + 2.13$

7

A-14. IB Mathematics Standard Level Task: Final

Modelling shooting in netball

A4

Introduction

Research question: What projectile velocities and corresponding release angles must a 170cm tall netball shooter achieve in order to successfully shoot a goal?

Image 1 – My netball team, 2011

Netball is currently the most popular women's sport in Australia (The Daily Telegraph, 2016). It emerged in the early 20th century as a women's version of basketball, being a ball sport involving two teams of seven players, where goals are scored by throwing a ball into a hoop (Netball Australia, n.d.). Unlike in basketball, however, there is no backboard behind the hoop in netball and players are not allowed to move whilst holding the ball. Netball is now played in over 80 nations worldwide, being most common amongst Commonwealth countries (Netball Australia, n.d.).

Rationale

Having played netball for over 10 years (Image 1), I was interested to explore the relationship between mathematics and the sport. I usually play the position of Goal Attack; who's main role in the game is to shoot goals, and so I decided to investigate the mathematics of shooting.

When shooting, netball players must vary the angle at which they release the ball based on the height of their defender. In order to ensure the ball still goes through the hoop, the player must also vary the velocity at which they throw the ball accordingly.

Clear Aim

Ultimately, the aim of my investigation was to determine the projectile velocities and corresponding release angles which would allow a shooter of my own height (170cm) to successfully shoot a goal. In doing so, I hoped to gain a deeper understanding of the way in which I must vary the velocity at which I throw the netball when shooting at different angles in the presence of defenders. I chose this topic as I felt that it had significant real world applications in the field of netball, giving insight into the mathematical side of shooting.

Plan of action

Organisation A4

1. I created a basic model for shooting a netball into a hoop, and used this model to determine the angle at which a player must release the ball to successfully shoot a goal at a set velocity.
2. I verified the accuracy of my results both graphically and algebraically.
3. I repeated this process with a range of velocities.

1

Finding the physical constants involved in the problem

A4

In netball, shooting must occur within a goal circle with a radius of 4.9m (see Diagram 1). For the purpose of the model, I assumed that the shooter was shooting from a distance of 2m away from the hoop (within the goal circle), as this is a normal distance that a person would shoot from. However, this assumption does limit the usefulness of the model in its applications to the game of netball, as in a real game this distance would vary considerably from shot to shot. good reflection D2

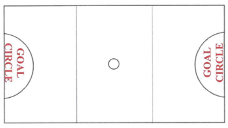


Diagram 1 – Layout of a netball court, with goal circle location indicated.
Source - http://mylearningjourneyub.global2.vic.edu.au/netball/

C3 D2

It is estimated that shooters, on average, tend to release balls at a height of approximately 125% their own height. (Gablonsky, J., Lang, A., 2005). I determined the height at which a shooter of my own height (170cm) would release the ball (Y_r) based on this assumption. It is noted that this figure is not entirely reliable, as the height at which I shoot the ball would vary with each shot.

$$Y_r = 170 \times 1.25$$
$$Y_r \approx 213cm$$

D2 - good observation/reflection

The international rules of netball (International Netball Foundation, 2015) do not provide the length of the diameter of a standard netball, however they do provide the circumference. I presume that this is because circumference is more practically measurable. The circumference (C) of a regulation size small netball is 690 – 710mm (International Netball Foundation, 2015). I based my calculations around the larger limit of the range of circumference sizes (710mm), as a ball of this size would be the hardest to shoot with. I used this circumference size to determine the diameter of the netball (D_b), where r is the radius of the netball.

$$C = 2\pi r$$
$$C = \pi D_b$$
$$700 = \pi D_b$$
$$D_b \approx 223mm$$

I found the acceleration of the ball due to gravity (g) from an online source (Soft Schools, n.d.). I sourced the rim diameter (D_b) and hoop height (Y_h) from the rules of netball (International Netball Foundation, 2015). I converted all the values into millimetres for convenience, except the balls acceleration due to gravity which was left in its conventional form.

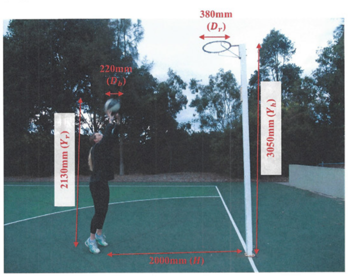
2

Table 1 - Physical constants involved in the problem

Physical Constant	Symbol	Value
Horizontal distance travelled	H	2000mm
Rim diameter	D_r	380mm
Ball diameter	D_b	220mm
Hoop height	Y_h	3050mm
Ball release height	Y_r	2130mm
Acceleration due to gravity	g	-9.81ms^{-2}

B3

Image 2 – Photograph of me shooting a netball, showing physical constants visually (diagram not to scale)



B3

Good personal engagement C3.

3

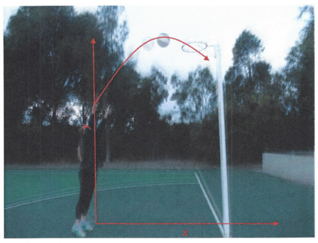


Image 3 – Photograph of me shooting a netball, showing the trajectory of the ball

Nice overall of a cartesian plane C3

C3 good personal engagement.

I used a rapid shoot mode on my camera to photograph the trajectory of a netball shot. I reduced the transparency of the images and layered them on top of each other to give a visual representation of the trajectory of the ball, measured from the centre of the ball. The curve of the trajectory represented in the image is not completely accurate due to the angle at which the photo was taken, however it does allow basic observations about the balls trajectory to be made. good reflection D2

From the graph, it is evident that the balls trajectory creates a concave down parabola, with a turning point between the x value at which the ball is released and the x value of the hoop. The dimensions of this parabola would vary from shot to shot.

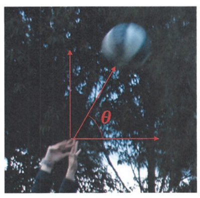


Image 4 – Photograph of me shooting a netball, showing the release angle (θ) of the ball

4

Resolving the initial velocity of the ball into horizontal and vertical components

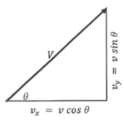


Diagram 2 – Resolving the initial velocity of the ball into horizontal and vertical components.

To find an equation to model the movement of a netball in a diagonal direction, I began by resolving the initial velocity of the ball (V) into vertical (v_y) and horizontal (v_x) equations (Diagram 2).

$$v_y = V \sin\theta \quad (1)$$
$$v_x = V \cos\theta \quad (2)$$

I derived an equation for the vertical acceleration of the ball (y''), considering the ball would accelerate along the y axis at -9.81ms^{-2} due to gravity (g) (Soft Schools, n.d.).

$$y'' = -9.81ms^{-2} = g$$

I integrated this equation in respect to t to derive an equation of the vertical velocity of the ball.

$$y' = \int y''\, dt$$
$$y' = -gt + c$$

I substituted the equation of the vertical component of the initial velocity of the ball (1) into this equation when $t = 0$, in order to find the constant (c).

$$V \sin\theta = -g(0) + c$$
$$\therefore c = V \sin\theta$$
$$\therefore y' = -gt + V \sin\theta$$

E6

I integrated the equation again to create a function for the vertical displacement of the ball.

$$y(t) = \int y'\, dt$$
$$y(t) = \frac{-gt^2}{2} + Vt \sin\theta + c$$

I found the value of the constant (c), by substituting the y value of the ball at time 0 (which would be 2130mm for a person of my height) into the equation, being the height at which the ball was released.

$$2130 = \frac{-g(0)^2}{2} + V(0) \sin\theta + c$$
$$c = 2130$$

5

This left me with a final function for the vertical displacement of the ball.

$$y(t) = \frac{-gt^2}{2} + Vt \sin\theta + 2130 \quad (3)$$

I then derived an equation for the horizontal acceleration of the ball, considering the ball would accelerate along the x axis at 0ms^{-2} (Soft Schools, n.d.).

$$x'' = 0$$

I integrated this equation in respect to t to derive an equation for the horizontal velocity of the ball, substituting in the equation of the horizontal component of the initial velocity of the ball when $t = 0$ (2) to find the constant (c).

$$x' = \int x''\, dt$$
$$x' = c$$
$$V \cos\theta = c$$
$$x' = V \cos\theta$$

I integrated the equation again to create a function for the horizontal displacement of the ball.

$$x(t) = Vt \cos\theta + c$$

I found the value of the constant (c), by substituting the x value of the ball at time 0, being 0m.

$$0 = V(0) \cos\theta + c$$
$$c = 0$$

E6

This left me with a final function for the horizontal displacement of the ball.

$$x(t) = Vt \cos\theta \quad (4)$$

Creating a final equation for velocity of the ball in a diagonal direction

I rearranged the function that I had previously derived for the horizontal displacement of the ball (4) to create an equation with time (t) as the subject.

$$x = vt \cos\theta$$
$$t = \frac{x}{v \cos\theta}$$

6

I then substituted this equation into the function I had previously derived for the vertical displacement of the ball (3).

$$y = \frac{-g\left(\frac{x}{v \cos\theta}\right)^2}{2} + v \frac{x}{v \cos\theta} \sin\theta + 2130$$

E6

I simplified this equation to create an equation for the velocity of the ball in a diagonal direction.

$$y = -\frac{gx^2}{2v^2} \sec^2\theta + x \tan\theta + 2130 \quad (5)$$

This equation models the trajectory of a netball. It is noted that a parameter of the equation would be that the release angle must be 0 < θ < 90° because the ball must be thrown in a forwards' direction to reach the hoop.

good observation D2

Limitations of the model

Air resistance - The equation does not take into account does not take into account the effect of air resistance on the motion of the shot. However, the impact of air resistance would be very minor so the omission of this factor does not significantly affect the accuracy of the model (Gablonsky, J., Lang, A., 2005).

Sideways motion - I also assumed that the shooter shot straight ahead, and did not allow for the sideways movement of the ball, the model being two-dimensional rather than three-dimensional.

Applying the model

In order to pass through the hoop, the balls trajectory must pass through the values corresponding to the horizontal value of the center of the netball hoop and the vertical height of the netball hoop. This is not entirely correct, as some netball shots involve the netball bouncing off the edge of the hoop, rather than passing directly through its centre, however I did not account for these shots in my model. I determined the x value of the center of the netball hoop (x_{cr}) by adding the horizontal distance travelled by the ball (H) to half of the diameter of the rim of the hoop (D_r).

good observation. reflection D2.

$$x_{cr} = H + \frac{D_r}{2}$$
$$x_{cr} = 2000 + \frac{380}{2}$$
$$x_{cr} = 2130$$

The y value of the center of the netball hoop is equivalent to the height of the netball hoop from the ground (3050mm). I substituted the point corresponding to the center of the netball hoop into the equation of the trajectory of the ball (5) to obtain the release angle of the ball (x). I kept the velocity (v) constant at 6.5ms^{-1}, as otherwise there would have been too many variables to solve the equation. I chose this value based on the average velocity of a basketball shot (Walker, n.d.).

$$y = x \tan\theta - \frac{gx^2}{2v^2} \sec^2\theta + 2130$$

7

$$3050 = 2190 \tan\theta - \frac{9810 \times 2190^2}{2 \times 6500^2} \sec^2\theta + 2130$$

in mm/s

I simplified this equation to make it easier to solve, the solution being given in radians and degrees.

Note: Although I have shown my intermediate results as approximate and rounded values, I did not use any rounded values in my calculations as oversimplification may lead to inaccuracies.

$$0 = \frac{-9810 \times 2190^2}{2 \times 6500^2} (1 + \tan^2\theta) + 2190 \tan\theta - 920$$
$$0 = -556.8 \tan^2\theta + 2190 \tan\theta - 1476.8$$
$$\tan\theta \approx 3.07 \text{ or } 0.86$$
$$\theta \approx 1.26^c \text{ or } 0.71^c$$
$$\theta \approx 72.0° \text{ or } 40.8°$$

Both of these release angles would result in trajectories which pass through the point corresponding to the center of the hoop. To determine which of these two angles would result in a shot, however, I needed to determine the gradients of the tangents of two trajectories at this point and investigate which of these gradients would allow the ball to pass through the hoop.

The path of the trajectory of the ball is given by

$$y = -\frac{gx^2}{2v^2} \sec^2\theta + x \tan\theta + 2130$$

The gradient of this function at any point can be determined by its derivative.

$$\frac{dy}{dx} = \tan\theta - \frac{gx}{v^2} \sec^2\theta$$

I substituted the first possible value of θ (0.71^c) as well as the coordinates of the center of the netball hoop (2190, 3050) into the equation, to determine the gradient of the trajectory at the point at which the ball would enter the hoop.

$$\frac{dy}{dx} = \tan(0.71) - \frac{9810 \times 2190}{6500^2} \sec^2(0.71)$$
$$\frac{dy}{dx} \approx -0.02$$

E6

I used this gradient to determine the angle at which the ball would enter the hoop.

$$\frac{rise}{run} \approx -0.02$$
$$\therefore \tan\theta \approx -0.02$$
$$\theta \approx 1.4°$$

8

This angle is almost horizontal, suggesting that this value of θ (0.71^c) would not result in a shot, however to verify this observation I had to determine the range of angles of entry that would allow a netball to enter the hoop. Before doing this, I determined the angle at which the ball would enter the hoop according to the second possible value of θ (1.26^c), in the same way as I had previously. I found that the ball would enter the hoop at an angle of approximately 65.8°.

What angles of entry allow a netball to enter the hoop

The angle at which the ball enters the hoop cannot exceed 90° due to the direction that it is thrown from. In an ideal netball shot, the ball would pass vertically through the center of the netball ring. However, this is rarely the case. Usually, the ball passes through the hoop at a slight angle. At a specific angle, however, the balls projected diameter will exceed the diameter of the ring, meaning that it will not result in a shot.

At the smallest angle through which the ball is able to pass through the hoop, the projected diameter of the ball (D_p) must be equal to the diameter of the hoop (D_r).

$$D_r = D_p$$

$$\therefore D_p = 380mm$$

The diameter of the ball (D_b) and the balls projected diameter (D_p) can be used to find the angle at which the ball enters the hoop (θ).

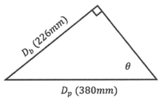


Diagram 3 – Determining the possible angles of entry of a netball into a hoop

$$\sin\theta = \frac{226}{380}$$

$$\theta \approx 36.5°$$

Therefore, the ball will pass through the ring if

$$36.5° < \theta < 90°$$

The angle 36.5° would be achieved by the lowest projectile velocity or projectile angle, and the angle 90° would be achieved by the highest projectile velocity or projectile angle.

E6.

As I determined previously, the first possible value of θ (40.8°) would result in the ball entering the hoop at an angle of 1.4°. This angle is smaller than 36.5°, thus would not result in a shot. D2

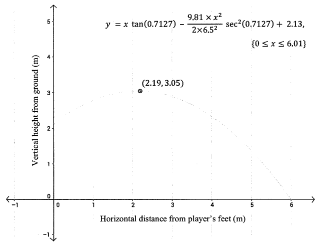
The second value of θ (72.0°) which would result in the ball entering the hoop at an angle of 65.8°, would result in a shot, as 36.5° < 65.8° < 90°.

Verifying my results graphically

To confirm the accuracy of my calculations, I graphed the trajectories of the ball when thrown at the angles of 72.0° and 40.8° with a velocity of 6.5ms^{-1}. I converted the measurements into metres.

9

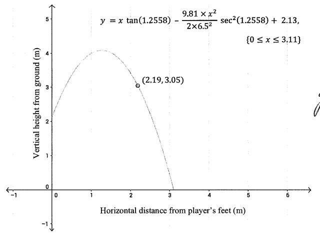
Graph 1 – Graph of the trajectory of a netball when thrown at an angle of 40.8°



good presentation
E6

In this trajectory, the ball would hit the hoop (2.19, 3.05) rather than passing through it, due to the gradient of the tangent at this point which is almost horizontal.

Graph 2 – Graph of the trajectory of a netball when thrown at an angle of 72.0°



good presentation
E6

In this trajectory, the ball reaches a maximum height at the point (1.27, 4.08), before falling back down through the hoop, resulting in a shot.

10

Extending my investigation to other velocities

I substituted a range of velocities into the equation of the trajectory of the ball (5), determining the optimum release angle at which the ball should be thrown in each case to achieve a goal, as I had done previously with the velocity 6.5ms^{-1}. I found that there were no solutions to velocity values below 5.75ms^{-1}. Graphing these trajectories, I realized that this would have been because the ball was not thrown with enough force to reach the hoop.

Table 2 – Table showing the optimum release angles of a range of velocities

Velocity (ms^{-1})	Optimum release angle (°)
5.75	61.1
6.00	66.6
6.25	69.7
6.50	72.0
6.75	73.7
7.00	75.2
7.25	76.5
7.50	77.6

E6.

The results in the table demonstrate that as the release angle of the ball increases, the velocity at which the ball is thrown must also increase in order to achieve goals. This is because as the release angle increases, the vertical displacement of the ball increases, meaning the ball must be thrown with more force to achieve a goal.

I did not include velocities above 7.5ms^{-1} in the table as this resulted in the balls trajectory reaching a maximum height of over 2m above the height of the netball hoop, which is unrealistic to a normal netball shot. Furthermore, players do not usually shoot at angles larger than 77.6° in netball, as defenders are rarely tall enough for this to be necessary.

Conclusion

A4.

Through my investigation, I was able to find a range of velocities and optimum release angles at which a 170cm player must shoot in netball in order to achieve a goal, thus fulfilling my aim. My results indicated that as the release angle of the ball increases, the velocity at which the ball is thrown must also increase in order to achieve goals. These results have real life applications, suggesting that it is necessary to increase the force at which the ball is thrown when shooting over taller defenders. This also provides a possible reason why goal keepers tend to be tall players, making it more difficult for players to shoot.

The investigation did have a number of limitations, for example, the model that was derived for the shooting of the netball was highly simplistic, and did not take into account air resistance or sideways motion, limiting the accuracy of the results.

Furthermore, my calculations are only applicable to shooters of height 170cm, shooting at a distance of 2m away from the hoop, as variations in these two variables would affect the results. Thus, a useful extension of the investigation would be to look at the relationship between projectile velocities and release angles for players of different heights, or at different distances away from the hoop.

11

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A4.

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12

A-15. IB Mathematics Standard Level Task: Grading

Title: Modelling shooting in netball

Criterion	A	B	C	D	E	Total
Achievement level awarded	4	3	3	2	6	18
Maximum possible achievement level	4	3	4	3	6	20

Comments

Criterion A: Communication

A4 – The paper is well organised, coherent and concise.

Criterion B: Mathematical Presentation

B3 – Appropriate throughout the paper. Tables, graphs and formula are used very well throughout the paper

Criterion C: Personal engagement

C3 – There is evidence of significant personal engagement throughout the paper. The student has looked at the problem in a creative manner.

Criterion D: Reflection

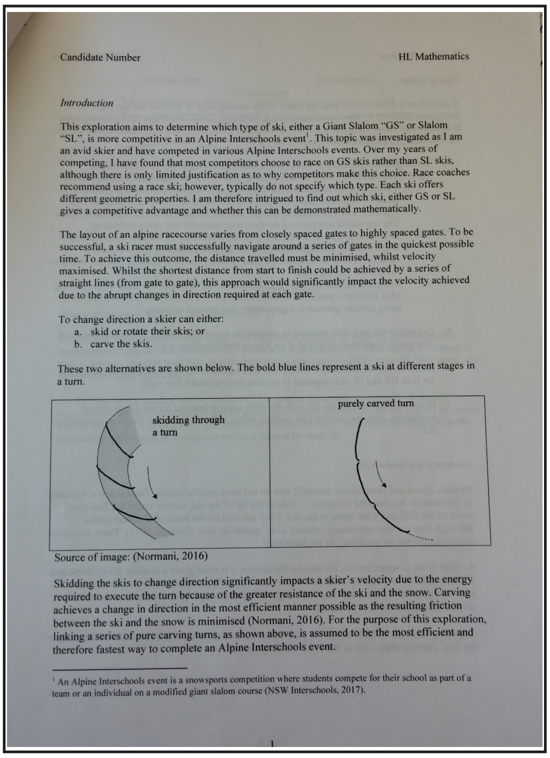
D2 – there is evidence of meaningful reflection throughout the paper.

Criterion E: Use of mathematics

E6 – Relevant mathematics commensurate with the course was used and the mathematics is correct. Thorough knowledge and understanding is demonstrated.

A-16. IB Mathematics Higher Level Task

Sample of 4 pages from Philip's daughter's IB task submission.



Candidate Number HL Mathematics

Introduction

This exploration aims to determine which type of ski, either a Giant Slalom "GS" or Slalom "SL", is more competitive in an Alpine Interschools event[1]. This topic was investigated as I am an avid skier and have competed in various Alpine Interschools events. Over my years of competing, I have found that most competitors choose to race on GS skis rather than SL skis, although there is only limited justification as to why competitors make this choice. Race coaches recommend using a race ski; however, typically do not specify which type. Each ski offers different geometric properties. I am therefore intrigued to find out which ski, either GS or SL gives a competitive advantage and whether this can be demonstrated mathematically.

The layout of an alpine racecourse varies from closely spaced gates to highly spaced gates. To be successful, a ski racer must successfully navigate around a series of gates in the quickest possible time. To achieve this outcome, the distance travelled must be minimised, whilst velocity maximised. Whilst the shortest distance from start to finish could be achieved by a series of straight lines (from gate to gate), this approach would significantly impact the velocity achieved due to the abrupt changes in direction required at each gate.

To change direction a skier can either:

a. skid or rotate their skis; or
b. carve the skis.

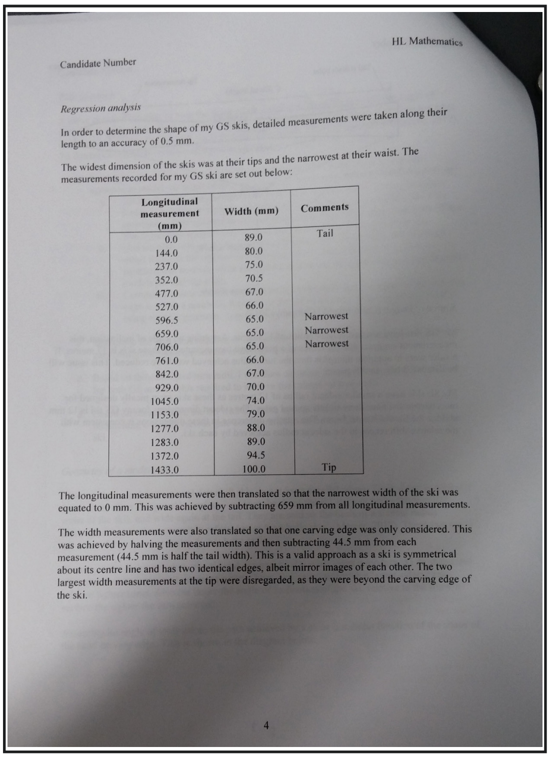
These two alternatives are shown below. The bold blue lines represent a ski at different stages in a turn.

Source of image: (Normani, 2016)

Skidding the skis to change direction significantly impacts a skier's velocity due to the energy required to execute the turn because of the greater resistance of the ski and the snow. Carving achieves a change in direction in the most efficient manner possible as the resulting friction between the ski and the snow is minimised (Normani, 2016). For the purpose of this exploration, linking a series of pure carving turns, as shown above, is assumed to be the most efficient and therefore fastest way to complete an Alpine Interschools event.

[1] An Alpine Interschools event is a snowsports competition where students compete for their school as part of a team or an individual on a modified giant slalom course (NSW Interschools, 2017).

1



HL Mathematics

Candidate Number

Regression analysis

In order to determine the shape of my GS skis, detailed measurements were taken along their length to an accuracy of 0.5 mm.

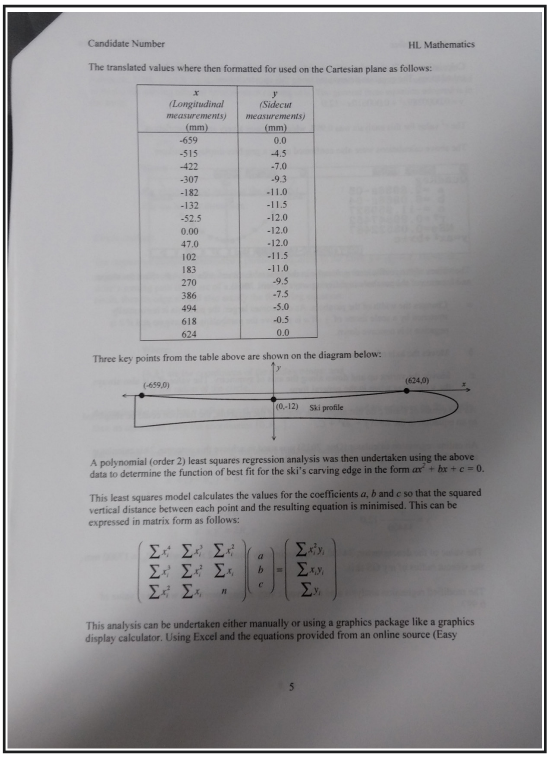
The widest dimension of the skis was at their tips and the narrowest at their waist. The measurements recorded for my GS ski are set out below:

Longitudinal measurement (mm)	Width (mm)	Comments
0.0	89.0	Tail
144.0	80.0	
237.0	75.0	
352.0	70.5	
477.0	67.0	
527.0	66.0	
596.5	65.0	Narrowest
659.0	65.0	Narrowest
706.0	65.0	Narrowest
761.0	66.0	
842.0	67.0	
929.0	70.0	
1045.0	74.0	
1153.0	79.0	
1277.0	88.0	
1283.0	89.0	
1372.0	94.5	
1433.0	100.0	Tip

The longitudinal measurements were then translated so that the narrowest width of the ski was equated to 0 mm. This was achieved by subtracting 659 mm from all longitudinal measurements.

The width measurements were also translated so that one carving edge was only considered. This was achieved by halving the measurements and then subtracting 44.5 mm from each measurement (44.5 mm is half the tail width). This is a valid approach as a ski is symmetrical about its centre line and has two identical edges, albeit mirror images of each other. The two largest width measurements at the tip were disregarded, as they were beyond the carving edge of the ski.

4



Candidate Number HL Mathematics

The translated values where then formatted for used on the Cartesian plane as follows:

x (Longitudinal measurements) (mm)	y (Sidecut measurements) (mm)
-659	0.0
-515	-4.5
-422	-7.0
-307	-9.3
-182	-11.0
-132	-11.5
-52.5	-12.0
0.00	-12.0
47.0	-12.0
102	-11.5
183	-11.0
270	-9.5
386	-7.5
494	-5.0
618	-0.5
624	0.0

Three key points from the table above are shown on the diagram below:

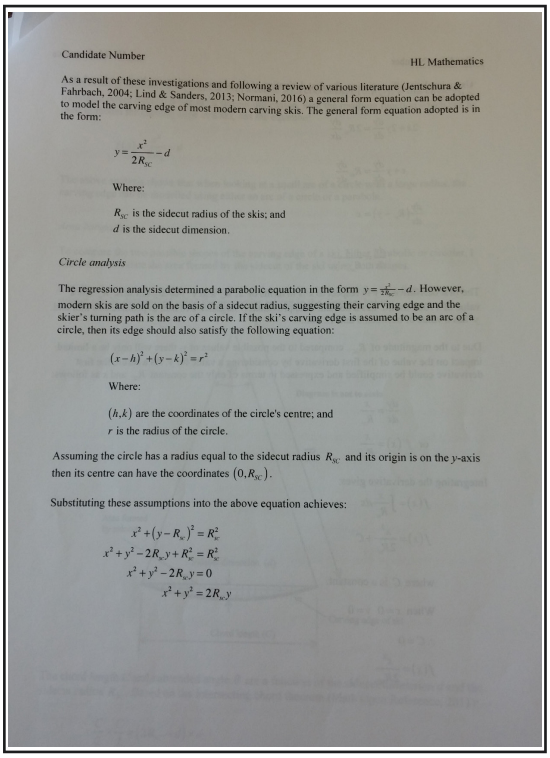
A polynomial (order 2) least squares regression analysis was then undertaken using the above data to determine the function of best fit for the ski's carving edge in the form $ax^2 + bx + c = 0$.

This least squares model calculates the values for the coefficients a, b and c so that the squared vertical distance between each point and the resulting equation is minimised. This can be expressed in matrix form as follows:

$$\begin{pmatrix} \sum x_i^4 & \sum x_i^3 & \sum x_i^2 \\ \sum x_i^3 & \sum x_i^2 & \sum x_i \\ \sum x_i^2 & \sum x_i & n \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} \sum x_i^2 y_i \\ \sum x_i y_i \\ \sum y_i \end{pmatrix}$$

This analysis can be undertaken either manually or using a graphics package like a graphics display calculator. Using Excel and the equations provided from an online source (Easy

5



Candidate Number HL Mathematics

As a result of these investigations and following a review of various literature (Jentschura & Fahrbach, 2004; Lind & Sanders, 2013; Normani, 2016) a general form equation can be adopted to model the carving edge of most modern carving skis. The general form equation adopted is in the form:

$$y = \frac{x^2}{2R_{SC}} - d$$

Where:

R_{SC} is the sidecut radius of the skis; and
d is the sidecut dimension.

Circle analysis

The regression analysis determined a parabolic equation in the form $y = \frac{x^2}{2R_{SC}} - d$. However, modern skis are sold on the basis of a sidecut radius, suggesting their carving edge and the skier's turning path is the arc of a circle. If the ski's carving edge is assumed to be an arc of a circle, then its edge should also satisfy the following equation:

$$(x-h)^2 + (y-k)^2 = r^2$$

Where:

(h,k) are the coordinates of the circle's centre; and
r is the radius of the circle.

Assuming the circle has a radius equal to the sidecut radius R_{SC} and its origin is on the y-axis then its centre can have the coordinates $(0, R_{SC})$.

Substituting these assumptions into the above equation achieves:

$$x^2 + (y - R_{sc})^2 = R_{sc}^2$$
$$x^2 + y^2 - 2R_{sc}y + R_{sc}^2 = R_{sc}^2$$
$$x^2 + y^2 - 2R_{sc}y = 0$$
$$x^2 + y^2 = 2R_{sc}y$$

A-17. Chesham House Year 7 Incursion Task

MANSW & Inquisitive Minds Strategy Lesson

Names:

26 POINTS

Warm up Questions

W1 *2 points*	W2 *2 points*	W3 *2 points*
W4 *4 points*	W5 *4 points*	W6 *4 points*
W7 *6 points*	W8 *6 points*	W9 *6 points*
W10 *8 points* 36 28 34	W11 *8 points*	W12 *8 points*

Bonus Questions

D1 *6 points*	D2 *6 points*	D3 *8 points*
P1 *6 points*	P2 *6 points*	P3 *8 points*
L1 *6 points*	L2 *6 points*	L3 *8 points*
T1 *6 points*	T2 *6 points*	T3 *8 points*

L1

	1	2	3	4	5	6
1	2	3	4	5	6	7
2	3	4	5	6	7	8
3	4	6	6	7	8	9
4	5	6	7	8	9	10
5	6	7	8	9	10	11
6	7	8	9	10	11	12

L2

CAPTAIN

VICE-CAPTAIN

	A	B	C	D	E
A			CA		
B					EB
C					
D					
E					

L3

	2	3	5	7										43	47
2															
3															
5															
7															
43															
47															

Mrs Collions

Ameliah phokes Lilly Petring

(14) points

Inquisitive Minds MANSW PPPP Hands-on Problem Solving Competition

1 Point Green Challenges

Question 1 string 5?	*Question 2* how far around A	*Question 3* dinner tables
Question 4 what's the chance A	*Question 5* secret sum 4 + 3 = 71	*Question 6* real time 1:35
Question 7 dividing area SHOW YOUR ANSWER TO A TEACHER	*Question 8* know australia A A A	*Question 9* order matters A A A

Total 1 point questions =

2 Point Blue Challenges

Question 10 rectangular strips A A A	*Question 11* whose name Kirby A A A	*Question 12* divisible by three 5826 A A
Question 13 fractional triangle	*Question 14* hidden faces 18	Question 15 how many red A A A
Question 16 fencing a farm SHOW YOUR ANSWER TO A TEACHER	*Question 17* non-adjacent counters SHOW YOUR ANSWER TO A TEACHER	*Question 18* coloured circles SHOW YOUR ANSWER TO A TEACHER

Total 2 point questions =

4 Point Red Challenges

Question 19 surf or skate A A A	*Question 20* matchstick patterns A A A	*Question 21* 30 counters
Question 22 mystery numbers A A	*Question 23* transforming grids A A A	Question 24 four matchsticks
Question 25 dotty dodecahedron SHOW YOUR ANSWER TO A TEACHER	*Question 26* net of a die 1, 3, 7, 5, 4, 6, 2, 8 A A A	Question 27 upside down SHOW YOUR ANSWER TO A TEACHER

Total 4 point questions =

Inquisitive Minds MANSW PPPP Hands-on Problem Solving Competition

6 Point Yellow Challenges

Question 28 consecutive counters SHOW YOUR ANSWER TO A TEACHER	*Question 29* folding napkins A A A	*Question 30* ed's seat
Question 31 subtracting dice A A A	*Question 32* crossing circles A A A	*Question 33* two patterns A A

Total 6 point questions =

8 Point Orange Challenges

You need a purple lanyard to attempt these questions.

Question 34 blank faces 9, 6, 5	*Question 35* painting area	*Question 36* orange squares A A A
Question 37 position position A A A	*Question 38* coloured faces SHOW YOUR ANSWER TO A TEACHER A A A	*Question 39* identical cubes G, R, B A A

Total 8 point questions =

10 Point White Challenges

You need a white lanyard to attempt these questions.

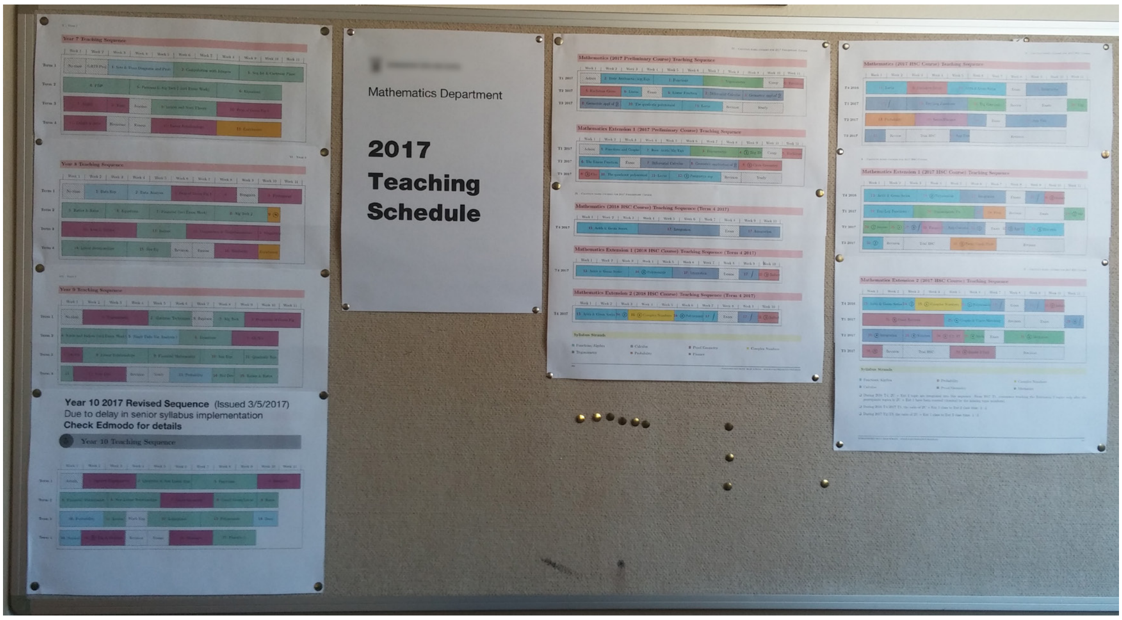
Question 40 dividing rectangles	*Question 41* tracing cubes	*Question 42* pentominoes SHOW YOUR ANSWER TO A TEACHER
Question 43 jesse's lollies A A	*Question 44* chessboard	*Question 45* five digits

Total 10 point questions =

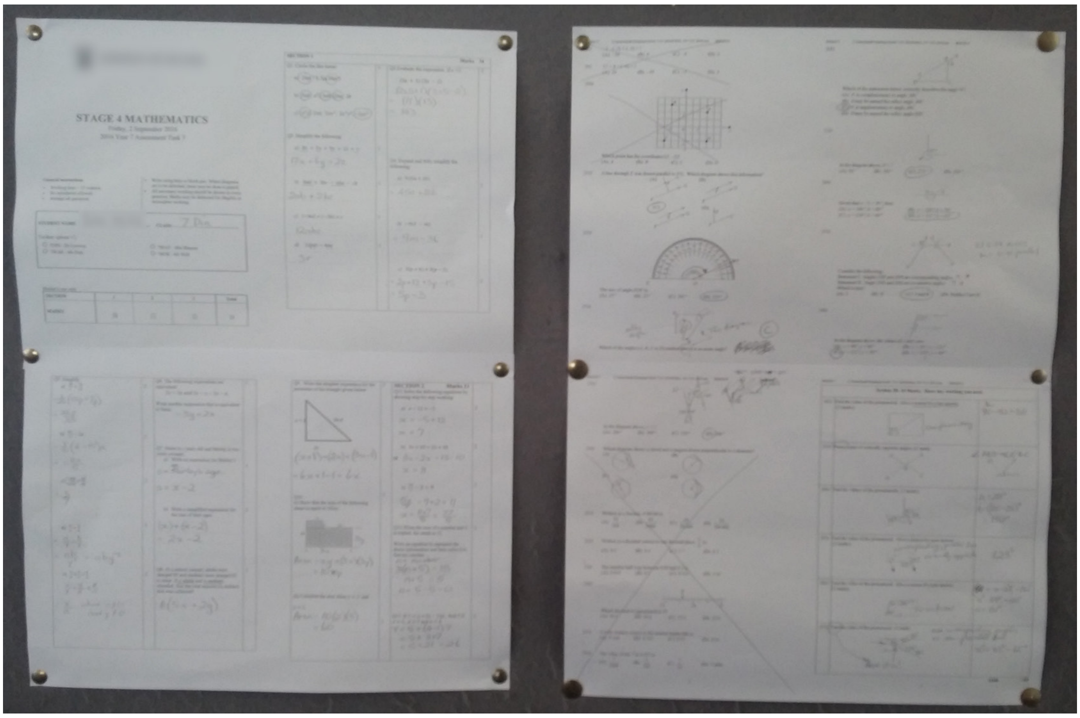
Names:

Total Points:

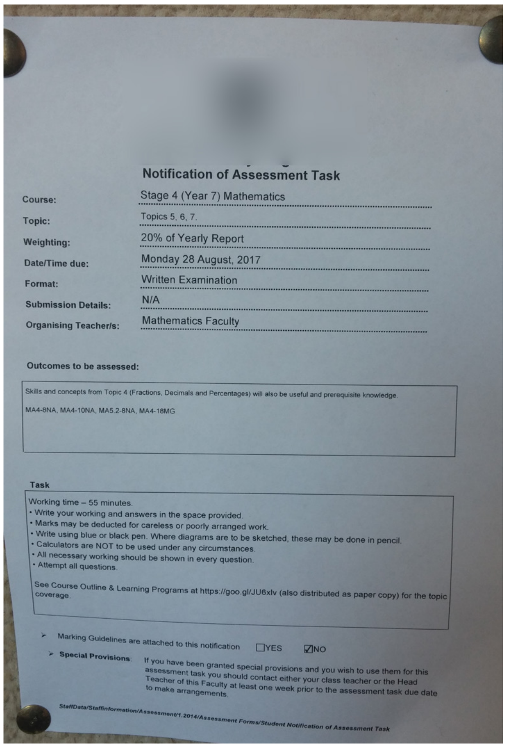
A-18. Elm Park High School Notices



Teaching schedule for all classes



Answers to a recent Year 7 examination



Notification of Assessment Task

Course: Stage 4 (Year 7) Mathematics
Topic: Topics 5, 6, 7.
Weighting: 20% of Yearly Report
Date/Time due: Monday 28 August, 2017
Format: Written Examination
Submission Details: N/A
Organising Teacher/s: Mathematics Faculty

Outcomes to be assessed:

Skills and concepts from Topic 4 (Fractions, Decimals and Percentages) will also be useful and prerequisite knowledge.
MA4-8NA, MA4-10NA, MA5.2-8NA, MA4-18MG

Task

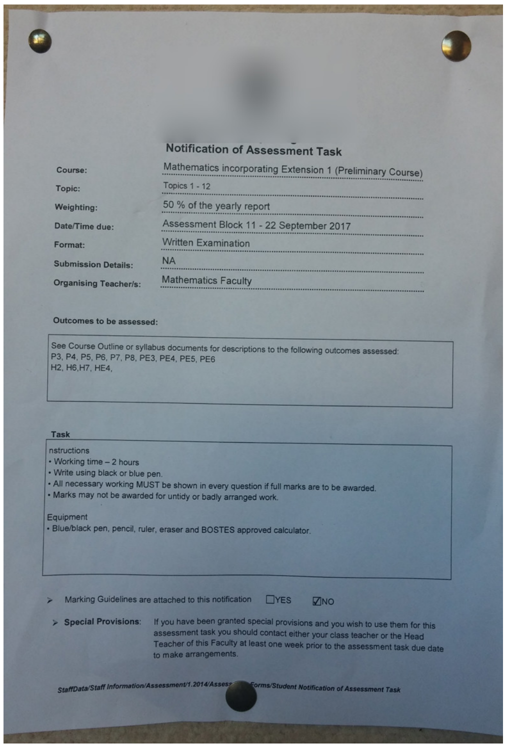
Working time – 55 minutes.
- Write your working and answers in the space provided.
- Marks may be deducted for careless or poorly arranged work.
- Write using blue or black pen. Where diagrams are to be sketched, these may be done in pencil.
- Calculators are NOT to be used under any circumstances.
- All necessary working should be shown in every question.
- Attempt all questions.

See Course Outline & Learning Programs at https://goo.gl/JU6xlv (also distributed as paper copy) for the topic coverage.

- Marking Guidelines are attached to this notification ☐YES ☑NO
- **Special Provisions**: If you have been granted special provisions and you wish to use them for this assessment task you should contact either your class teacher or the Head Teacher of this Faculty at least one week prior to the assessment task due date to make arrangements.

StaffData/StaffInformation/Assessment/1.2014/Assessment Forms/Student Notification of Assessment Task

Notification of Assessment: Year 7



Notification of Assessment Task

Course: Mathematics incorporating Extension 1 (Preliminary Course)
Topic: Topics 1 - 12
Weighting: 50 % of the yearly report
Date/Time due: Assessment Block 11 - 22 September 2017
Format: Written Examination
Submission Details: NA
Organising Teacher/s: Mathematics Faculty

Outcomes to be assessed:

See Course Outline or syllabus documents for descriptions to the following outcomes assessed:
P3, P4, P5, P6, P7, P8, PE3, PE4, PE5, PE6
H2, H6, H7, HE4,

Task

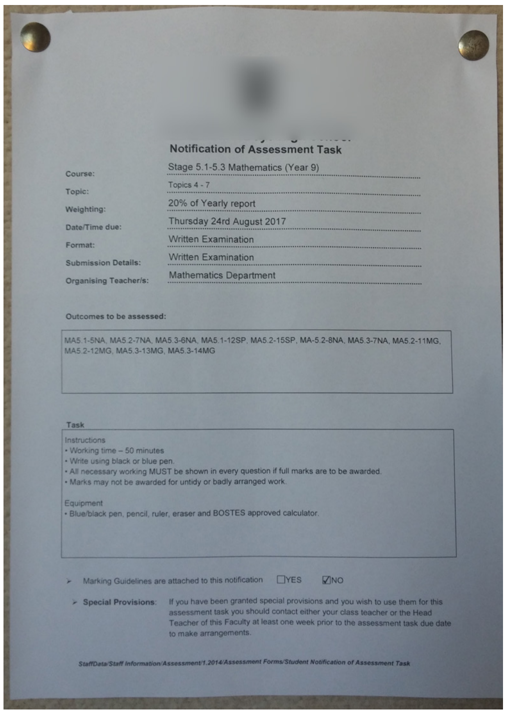
nstructions
- Working time – 2 hours
- Write using black or blue pen.
- All necessary working MUST be shown in every question if full marks are to be awarded.
- Marks may not be awarded for untidy or badly arranged work.

Equipment
- Blue/black pen, pencil, ruler, eraser and BOSTES approved calculator.

- Marking Guidelines are attached to this notification ☐YES ☑NO
- **Special Provisions**: If you have been granted special provisions and you wish to use them for this assessment task you should contact either your class teacher or the Head Teacher of this Faculty at least one week prior to the assessment task due date to make arrangements.

StaffData/Staff Information/Assessment/1.2014/Asses... Forms/Student Notification of Assessment Task

Notification of Assessment: Extension 1



Notification of Assessment Task

Course: Stage 5.1-5.3 Mathematics (Year 9)
Topic: Topics 4 - 7
Weighting: 20% of Yearly report
Date/Time due: Thursday 24rd August 2017
Format: Written Examination
Submission Details: Written Examination
Organising Teacher/s: Mathematics Department

Outcomes to be assessed:

MA5.1-5NA, MA5.2-7NA, MA5.3-6NA, MA5.1-12SP, MA5.2-15SP, MA-5.2-8NA, MA5.3-7NA, MA5.2-11MG, MA5.2-12MG, MA5.3-13MG, MA5.3-14MG

Task

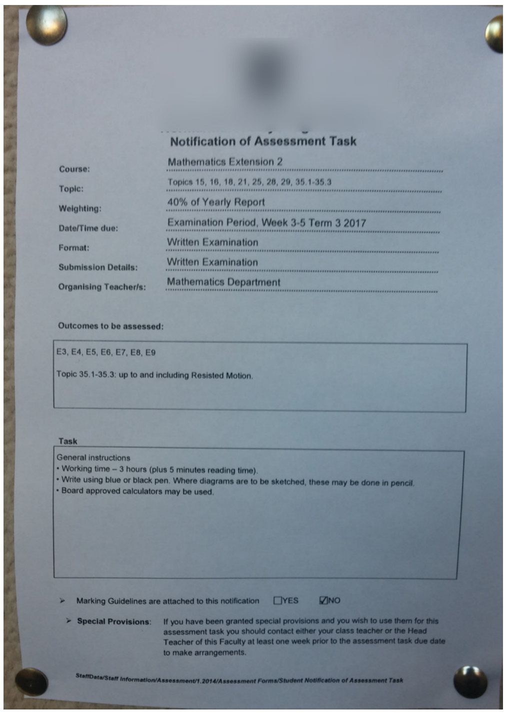
Instructions
- Working time – 50 minutes
- Write using black or blue pen.
- All necessary working MUST be shown in every question if full marks are to be awarded.
- Marks may not be awarded for untidy or badly arranged work.

Equipment
- Blue/black pen, pencil, ruler, eraser and BOSTES approved calculator.

- Marking Guidelines are attached to this notification ☐YES ☑NO
- **Special Provisions**: If you have been granted special provisions and you wish to use them for this assessment task you should contact either your class teacher or the Head Teacher of this Faculty at least one week prior to the assessment task due date to make arrangements.

StaffData/Staff Information/Assessment/1.2014/Assessment Forms/Student Notification of Assessment Task

Notification of Assessment: Year 9



Notification of Assessment Task

Course: Mathematics Extension 2
Topic: Topics 15, 16, 18, 21, 25, 28, 29, 35.1-35.3
Weighting: 40% of Yearly Report
Date/Time due: Examination Period, Week 3-5 Term 3 2017
Format: Written Examination
Submission Details: Written Examination
Organising Teacher/s: Mathematics Department

Outcomes to be assessed:

E3, E4, E5, E6, E7, E8, E9
Topic 35.1-35.3: up to and including Resisted Motion.

Task

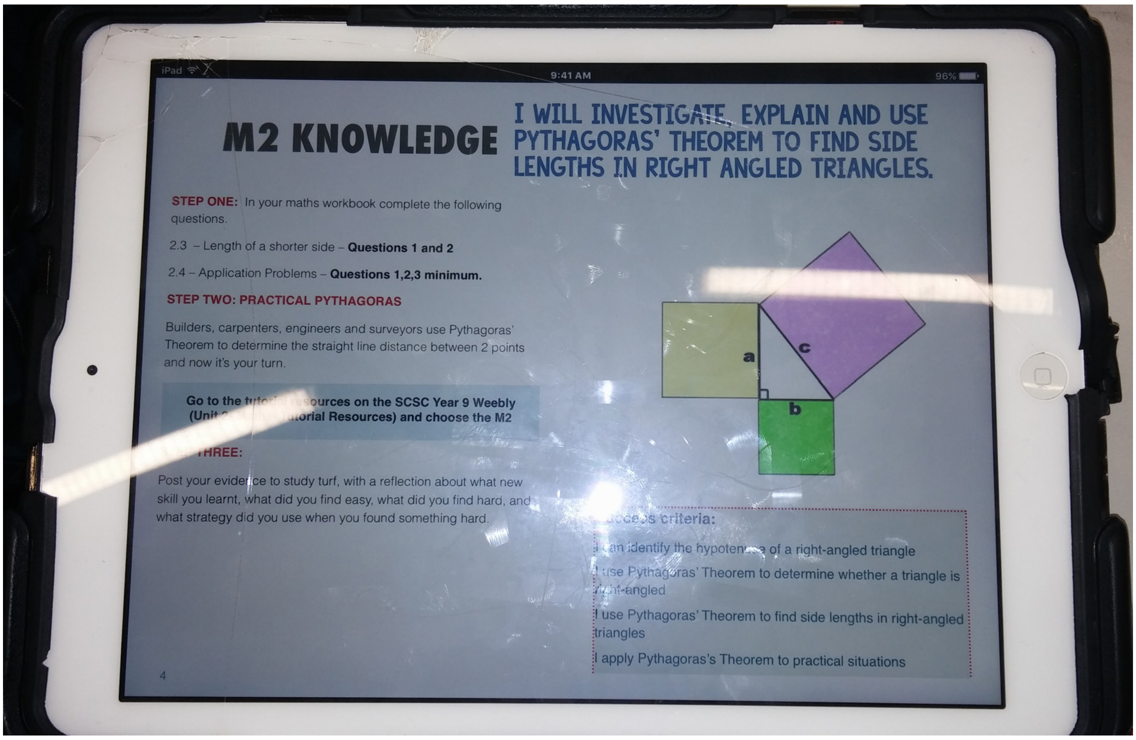
General instructions
- Working time – 3 hours (plus 5 minutes reading time).
- Write using blue or black pen. Where diagrams are to be sketched, these may be done in pencil.
- Board approved calculators may be used.

- Marking Guidelines are attached to this notification ☐YES ☑NO
- **Special Provisions**: If you have been granted special provisions and you wish to use them for this assessment task you should contact either your class teacher or the Head Teacher of this Faculty at least one week prior to the assessment task due date to make arrangements.

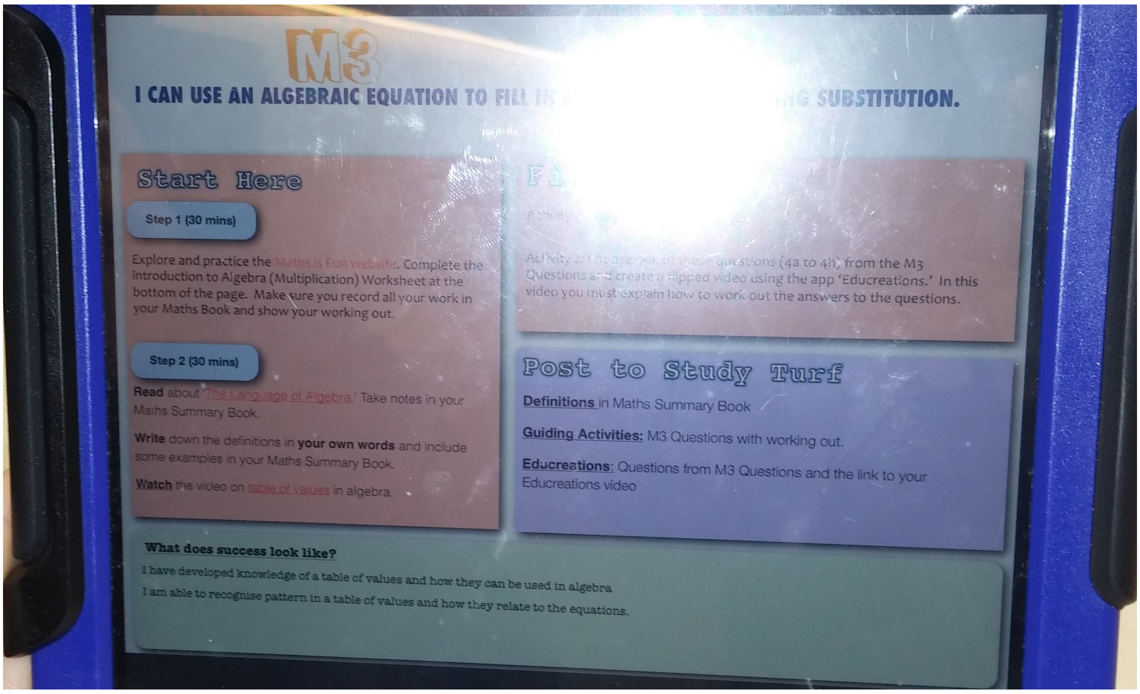
StaffData/Staff Information/Assessment/1.2014/Assessment Forms/Student Notification of Assessment Task

Notification of Assessment: Extension 2

A-19. Moorgate Secondary College Task Cards



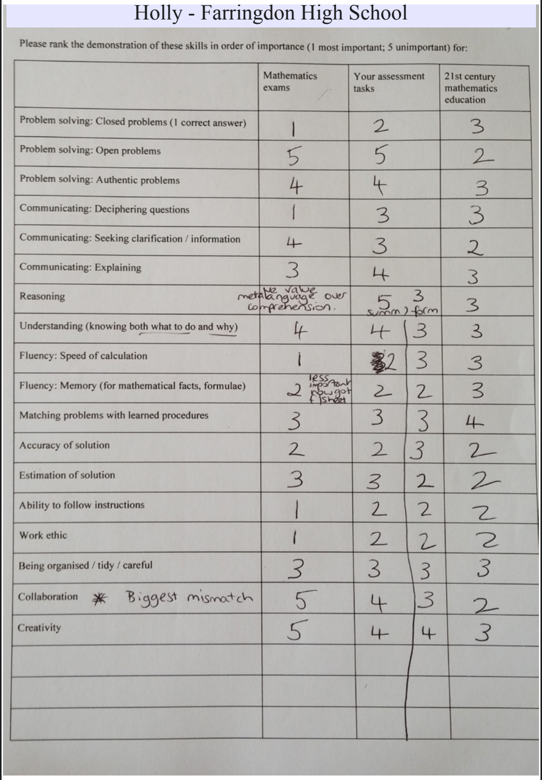
Level M2 Pythagoras task card.



Level M3 Algebraic Equations task card.

A-20. Importance of Skills Interview Prompt

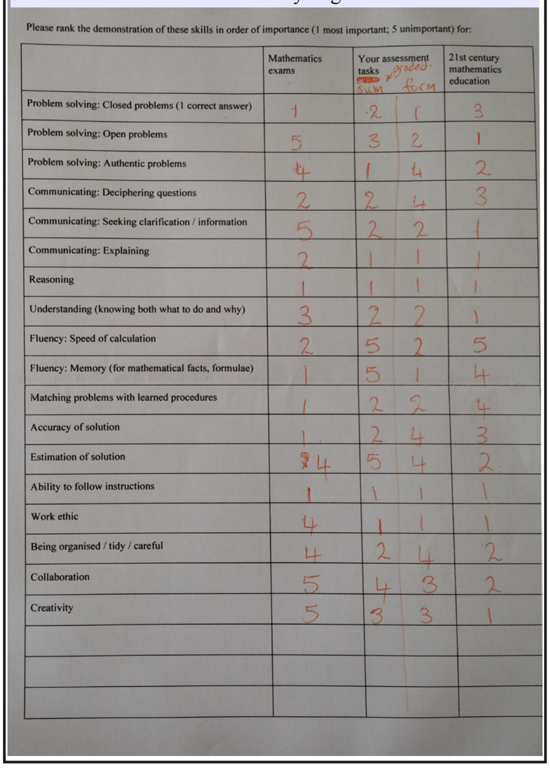
Holly - Farringdon High School



Please rank the demonstration of these skills in order of importance (1 most important; 5 unimportant) for:

	Mathematics exams	Your assessment tasks		21st century mathematics education
Problem solving: Closed problems (1 correct answer)	1	2		3
Problem solving: Open problems	5	5		2
Problem solving: Authentic problems	4	4		3
Communicating: Deciphering questions	1	3		3
Communicating: Seeking clarification / information	4	3		2
Communicating: Explaining	3	4		3
Reasoning	we value metalanguage over comprehension.	5 summ	3 form	3
Understanding (knowing both what to do and why)	4	4	3	3
Fluency: Speed of calculation	1	2	3	3
Fluency: Memory (for mathematical facts, formulae)	2 less important now got f sheet	2	2	3
Matching problems with learned procedures	3	3	3	4
Accuracy of solution	2	2	3	2
Estimation of solution	3	3	2	2
Ability to follow instructions	1	2	2	2
Work ethic	1	2	2	2
Being organised / tidy / careful	3	3	3	3
Collaboration * Biggest mismatch	5	4	3	2
Creativity	5	4	4	3

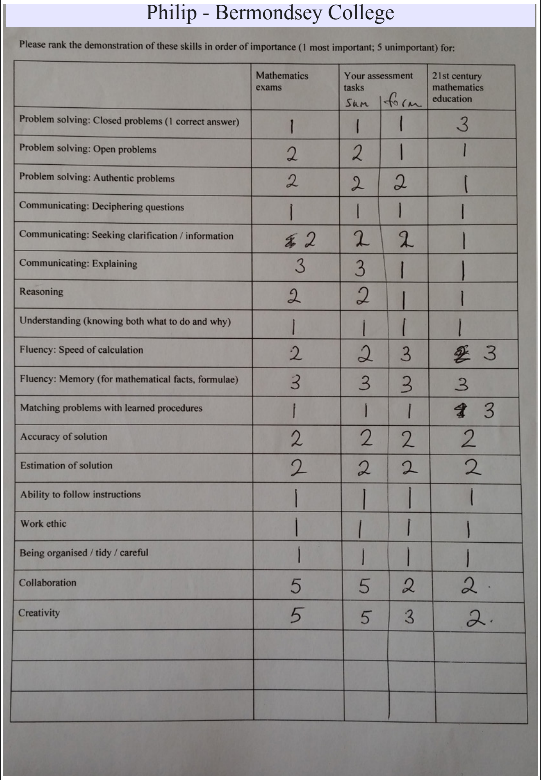
Elizabeth - Osterley High School



Please rank the demonstration of these skills in order of importance (1 most important; 5 unimportant) for:

	Mathematics exams	Your assessment tasks graded: sum	form	21st century mathematics education
Problem solving: Closed problems (1 correct answer)	1	2	1	3
Problem solving: Open problems	5	3	2	1
Problem solving: Authentic problems	4	1	4	2
Communicating: Deciphering questions	2	2	4	3
Communicating: Seeking clarification / information	5	2	2	1
Communicating: Explaining	2	1	1	1
Reasoning	1	1	1	1
Understanding (knowing both what to do and why)	3	2	2	1
Fluency: Speed of calculation	2	5	2	5
Fluency: Memory (for mathematical facts, formulae)	1	5	1	4
Matching problems with learned procedures	1	2	2	4
Accuracy of solution	1	2	4	3
Estimation of solution	4	5	4	2
Ability to follow instructions	1	1	1	1
Work ethic	4	1	1	1
Being organised / tidy / careful	4	2	4	2
Collaboration	5	4	3	2
Creativity	5	3	3	1

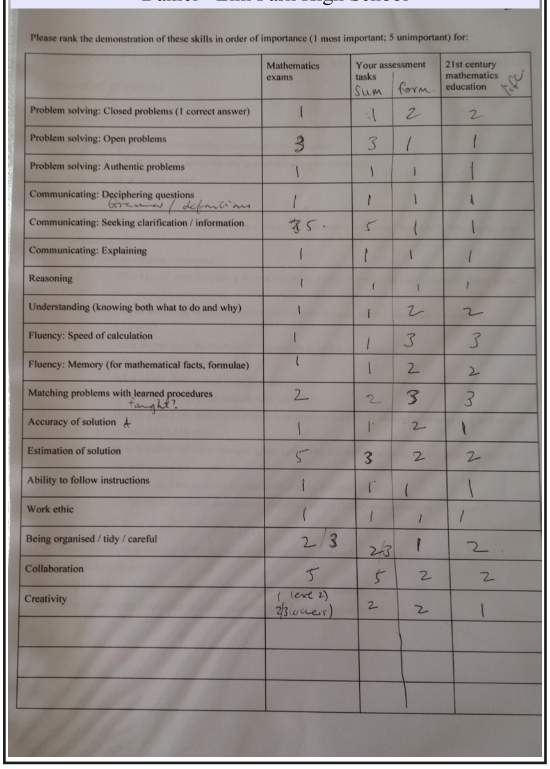
Philip - Bermondsey College



Please rank the demonstration of these skills in order of importance (1 most important; 5 unimportant) for:

	Mathematics exams	Your assessment tasks: Sum	form	21st century mathematics education
Problem solving: Closed problems (1 correct answer)	1	1	1	3
Problem solving: Open problems	2	2	1	1
Problem solving: Authentic problems	2	2	2	1
Communicating: Deciphering questions	1	1	1	1
Communicating: Seeking clarification / information	2	2	2	1
Communicating: Explaining	3	3	1	1
Reasoning	2	2	1	1
Understanding (knowing both what to do and why)	1	1	1	1
Fluency: Speed of calculation	2	2	3	3
Fluency: Memory (for mathematical facts, formulae)	3	3	3	3
Matching problems with learned procedures	1	1	1	3
Accuracy of solution	2	2	2	2
Estimation of solution	2	2	2	2
Ability to follow instructions	1	1	1	1
Work ethic	1	1	1	1
Being organised / tidy / careful	1	1	1	1
Collaboration	5	5	2	2
Creativity	5	5	3	2

Daniel - Elm Park High School



Please rank the demonstration of these skills in order of importance (1 most important; 5 unimportant) for:

	Mathematics exams	Your assessment tasks: Sum	form	21st century mathematics education
Problem solving: Closed problems (1 correct answer)	1	1	2	2
Problem solving: Open problems	3	3	1	1
Problem solving: Authentic problems	1	1	1	1
Communicating: Deciphering questions Grammar / definitions	1	1	1	1
Communicating: Seeking clarification / information	5	5	1	1
Communicating: Explaining	1	1	1	1
Reasoning	1	1	1	1
Understanding (knowing both what to do and why)	1	1	2	2
Fluency: Speed of calculation	1	1	3	3
Fluency: Memory (for mathematical facts, formulae)	1	1	2	2
Matching problems with learned procedures taught?	2	2	3	3
Accuracy of solution	1	1	2	1
Estimation of solution	5	3	2	2
Ability to follow instructions	1	1	1	1
Work ethic	1	1	1	1
Being organised / tidy / careful	2/3	2/3	1	2
Collaboration	5	5	2	2
Creativity	1 (exl 2) 2/3 (others)	2	2	1