10 Activity Theory used in an Educational Investigation

M. Coupland, K. Crawford

Introduction

In tertiary mathematics education, computer algebra systems (CAS) are complex new tools that automate many of the pen and paper skills that are used by students in schools and also by many university staff. The new leaning experiences can result in an epistemological shift as learner awareness shifts from the routine and laborious pencil and paper processes to interpreting and exploring a mathematical system. In a study of student conceptions of their experiences with this new tool, it became clear that their prior experiences with computers *and* their chosen level of engagement with mathematical learning *and* their attitudes to the tasks they were set interacted in complex ways that could be explained from an Activity theory perspective. Overall, successful adopters of the new technology tended to be those with extensive computer backgrounds. However, students with a high level of engagement in their mathematical learning (searching for personal meaning in their studies), and those (mostly older) students who were socially adept at group work, also had positive experiences even if their computer background was poor. In the personal pasts of the students and in the cultural-historical pasts of our institutions, being expert at following rules led to success in mathematics learning with paper technologies. In the emerging new learning

environments enabled by computer algebra systems, students who chose deeper approaches to learning than those that were rewarded in the past found their experience personally rewarding. There are evident contradictions between the behaviours that are rewarded by traditional formal teaching processes at University and the most effective approaches to learning to realize the potential of contexts enabled by computer algebra systems.

Context and significance

How do we explain the continuing presence of entrenched and constraining beliefs in education? How do we investigate the opportunities that are taken up and also that are missed when complex new tools are introduced into teaching and learning contexts? We need a framework that incorporates an awareness of the cultural-historical background to the social practices that are education. The framework needs to be scalable to reflect the proximal and distal (Pong and Morris, 2002) influences on individuals as they interact with each other and with cultural artefacts within a social structure.

Mathematics education is a particular example of a complex human activity with a long cultural historical background. As a field it is shaped by changes in the ways mathematics is made and used in society *and also* by changes in education. For example, in tertiary mathematics education we inherit a positivist paradigm that separates knowledge from knower and endorses transmissive practices that explain under-achievement in terms of students' lack of 'natural' ability and motivation. What is transmitted is a view of mathematics as 'finished' and polished. Students get the idea that there are always answers, even if they cannot find them themselves. In the wider community, mathematics is the underpinning knowledge embedded in many emerging complex socio-technical systems. With a greater understanding of complexity, mathematics is now made using new complex tools and applied in a way that may lead to unexpected and fluid results in almost every field of human activity.

The social construction of the terms and beliefs that shape educational practices in mathematics education is not often recognised or questioned (Dunne, 1994, 1999). We need a way to investigate why students bring with them to university views of mathematics and study approaches that are often unproductive (Crawford Gordon, Nicholas and Prosser 1994, 1998). We need to be able to understand the interactions of those beliefs with the new situations that students find themselves in when university study involves complex new computer software tools.

A research study was carried out to investigate the introduction of *Mathematica,* a Computer Algebra System (CAS) into the teaching and learning of mathematics in first year subjects at an Australian university. The main aim of the research was to investigate the diverse ways in which the students engaged with the new software, and whether or not they successfully appropriated it for their own use in mathematics or other areas of their study at university. Data in the form of surveys were collected from about 120 students, with a small number of follow up interviews.

Researching Multiple Perspectives

In undertaking this study we felt it essential to design research that was consistent with our beliefs about the multiple, and often idiosyncratic, perspectives of participants in any human activity, based on the varied individual histories of people and their differing roles and objectives. The data was collected in a way that elicited the diverse conceptions of the students and their lecturers of the situation. In order to allow for student voices to be heard, the survey questions were developed from comments originally made by students in pilot surveys. The final survey asked several open-ended questions so that a 'space' was created for the expression of individual opinions and beliefs. Follow up interviews were carried out to probe emerging issues and tensions and to flesh out and test the emerging perspectives.

Activity Theory as a Framework

Activity theory, as we use it, (see for example Wertsch 1979, Engeström 1987, Verenikina 2002) provides a valuable framework and explanatory tool for our research. It is scalable since an Activity[1] system can be viewed as an outline of a common activity shared by many, but also the perspective of individuals can be taken (e.g. Berglund and Booth 2002, Gordon 1998.). It also explains the multiple goals motivating people, each with an individual history of related activity, who are apparently engaged in similar behaviour as members of a community and how these perspectives shape their learning and emerging capabilities. From the point of view of individuals, activity theory describes the motivation of the 'object' of their activity within a community and the goals that individuals create for themselves based on their interpretation of that object. Importantly, an activity theory perspective incorporates the socio-cultural histories of individuals and of the communities with which they interact and to which they belong. The theory also describes the place of cultural artefacts (tools) of varying complexity. These tools bring with them the additional history of social practices of the past and associated human behaviour and beliefs. Activity theory allows us to understand changes as the activity system evolves because of tensions within it.

The relevant activity system

We propose the following model of the activity system of teaching and learning mathematics at first year, based on Engeström (1987).

[1] The upper case A is used to denote Activity in the sense used by the theorists of active and involved engagement in a situation. The usual meaning of the English activity does not carry the same sense of purpose and meaning.

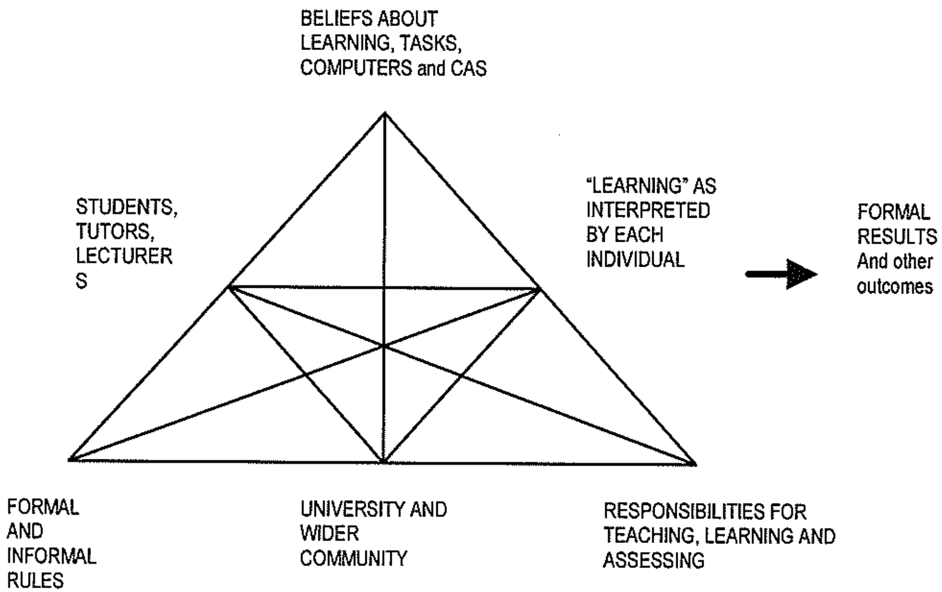

Figure 1 A model of the activity system of teaching and learning first year mathematics (After Engestrom, 1987)

Looking at the top of this triangle allows us to focus on the way that students acted towards their goals, using the computer algebra system (CAS) and the assessment tasks associated with the CAS in various ways. The data we collected is shown as well:

Data collected

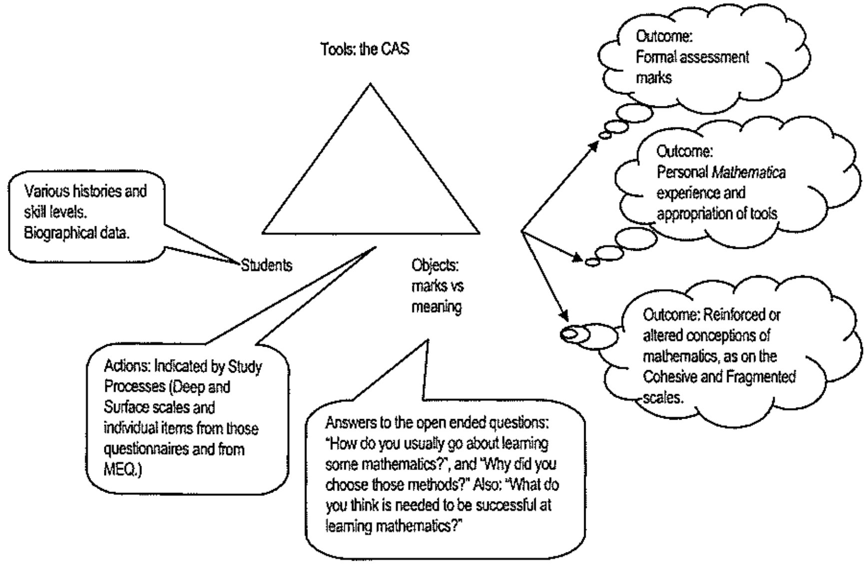

Figure 2 The top of the activity system triangle from figure 1

What did the students say about their background, their actions, and the outcomes? (A selection of the data collected, and analysis)

We used students' self reports of their biographical information, and to assess their computing background we asked "Overall, how would you rate your own computing background and experience?" with options of "Very limited", "Adequate for my study needs", "More than adequate for my study needs ", and

"Extensive". The first two categories were combined into "Low" and the second two into "High" computing background.

In Activity theory, actions and operations are fundamental units of analysis in any Activity. An Activity (subordinated to a subjective object) can be regarded as consisting of creatively constructed actions and more habitual operations that are directed towards goals, which are in turn constructed by individuals for themselves as they interpret the requirements of the Activity. Actions are consciously performed while operations are often highly automated and performed without conscious awareness. In formal education, a fundamental contradiction often exists between the immediate goal of gaining assessment marks, and a goal with longer term benefits: gaining personal understanding. The responses to three open-ended questions in our survey were analysed to gain an idea of the students' actions and goals in learning mathematics.

(1) How do you usually go about learning some maths? It may help to think about some maths you understood really well. How did you go about learning that?
(2) Regarding your answer to question 1, why did you choose those methods?
(3) What do you think is needed to be successful at learning mathematics?

The first question addresses the awareness of each individual about their previous experience and their actions and operations, and is similar to the questions posed to 300 first year university students by Crawford, Gordon, Nicholas and Prosser (1994). The second attempts to find the source (cultural historical origins) of beliefs about learning, and the third aims to find out about personal goals.

All responses were transcribed and a map was constructed to show how common responses to each of the three questions were related. Many of the responses to the first question were at the level of operations. Many students described completing

exercises in order to memorise and reproduce techniques for solving standard problems. Some responses went further and included actions such as reading notes studying worked examples, or goals such as aiming to understand concepts. A further group mentioned talking to others (fellow students, tutors, teachers...) and finally there was a small group who described striving for personal understanding.

With a small group of colleagues we engaged in three rounds of an iterative process, the result of which was a sorting of the responses into four nested categories. We call the categories *categories of engagement in mathematical learning.* At each round, borderline cases were discussed and the definitions of the categories were refined. The purpose here was to try to minimise any personal bias in the initial category building. The process we chose is consistent with the notion of knowledge building as a social process, where meanings are built up by discussion and negotiation. It is also consistent with the approach to qualitative analysis by researchers working collaboratively in groups as suggested by phenomenographers (Bowden, 2000).

Following are descriptions of each category and a set of "typical" responses for each of the four categories.

Illustrative responses for each category of engagement in mathematical learning.

The questions being asked were:

(1) How do you usually go about learning some maths? It may help to think about some maths you understood really well. How did you go about learning that?
(2) Regarding your answer to question 1, why did you choose those methods?
(3) What do you think is needed to be successful at learning mathematics?

Descriptions	**Illustrative comments**
A *(Mainly operational)* Practice many questions Memorise formulae Attend lectures, take notes *Intention is to pass exam, or intention may be unquestioned* *(The actions may be driven by habit rather than goal-directed.)*	(1) I do as many exercises as I can. (2) Because this is the method I have always used. (3) Good teachers and lots of practices.
B Includes A, also study worked examples and notes prepared by others *Intention is to be able to repeat the steps: operational but less rote learning*	(1) Studying heaps of examples and reading notes. (2) It helps me to understand what I am really looking for in the answer, as well as the concepts and ideas behind the topic studied. (3) Simple notes made by someone who knows what they are talking about. What I used to do is have a sheet of notes (simplified) and just add additional notes in class to help me. It's the best way to study because your focus is on the lecturer and not trying to keep up with writing notes.
C Includes A and B Consult with teachers, lecturers, tutors, other staff and students for help when stuck and/or for worked examples and explanations. May include doing exercises but with *the intention of understanding.* *Social actions are described here.*	(1) Read through the concept of the maths and during that time do examples of the concepts that are presented. Then do a whole exercise involving the maths. Check answers and redo any that are incorrect (if possible). Note any problems and seek advice from lecturer/ tutor/ maths study centre. (2) Helpful to do worked examples while reading through the concepts. Doing an exercise helps to solidify the concepts and bring attention to any problems I have with the concept. (3) Practice is important. Once I have an idea of the concept and have done worked examples, I practice by doing exercises and examples. Regular study of maths on a daily basis is also helpful.
D May include A, B, and C. Take various steps to achieve understanding of concepts, theory, derivation of formulae etc Reading other textbooks Visualising for oneself Reflection on notes *Actions on the internal personal plane.*	(1) Trying to understand how a principle came about, i.e. its origins, understanding what its applications are, and what information is necessary in order to use the formula, principle etc. Once this is done, I work through examples to straighten out any misinterpretation. (2) This avoids rote learning, merely being able to do something without fully understanding what it is you're doing. (3) A mind that can visualise concepts and organise given information into a way of solving a problem.

The MEQ (Mathematica Experience Questionnaire) consisted of 56 questions about the students' experiences with *Mathematica*, the CAS that all students used this semester. For nearly all students this was their initial experience with any CAS software. The items in the questionnaire were mainly constructed on the basis of student reports from previous semesters. Further details are given in Coupland (2000). A principle components analysis was conducted on a selection of those items, producing a three-component solution. The components were interpreted as describing three categories of response. These were "Useful" (indicating that students used the CAS for their own work in the relevant and other subjects), "Worth doing" (indicating that the time spent on the CAS activities did not detract from other requirements of the subject, and that the difficulty level was not so high as to make the CAS work not worthwhile), and "Enjoyed with others" (indicating that some students enjoyed the interactions with others that were stimulated by their laboratory and assignment work). In the activity theory framework, these can be considered as some of the outcomes of the activity of learning mathematics in a CAS environment.

What relationships were we expecting, and what did we find?

We expected that scores on the components of a successful experience with the CAS would be aligned with prior computing experience, as suggested by previous research (e.g. Galbraith, Haines, and Pemberton 1999). This did occur as shown in figure 3 below, but the differences were not as marked as we might have expected.

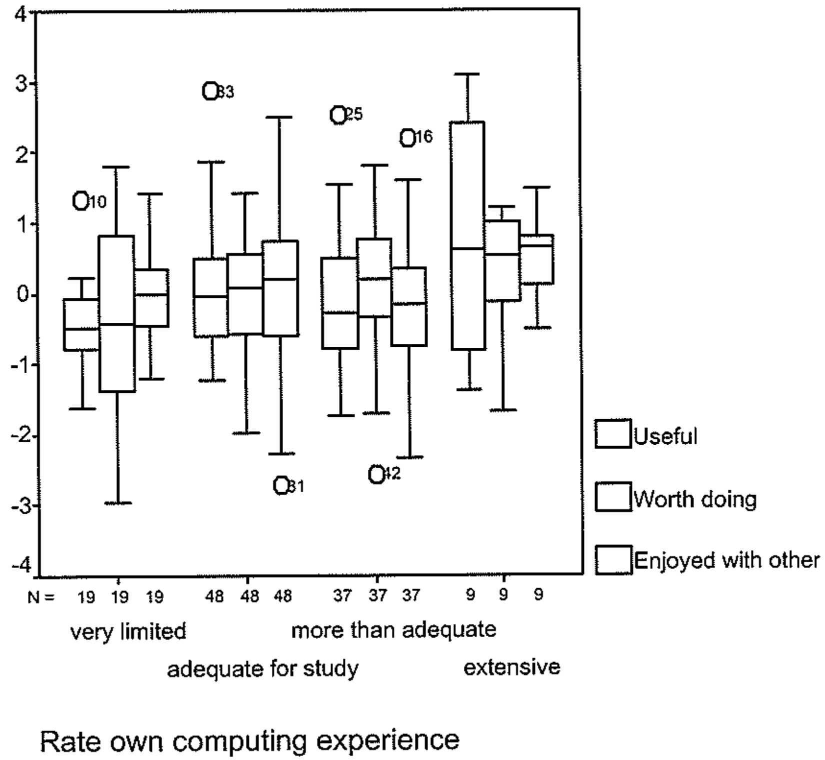

Figure 3 Scores on the three components of CAS experience, by reported level of prior computer experience

Since activity theory gives a prominent place to the goals and actions of individuals, as well as their personal history, we looked again at the three components of CAS experience, this time with different categories of engagement in mathematical learning broken down into high and low computing experience. The results were startling.

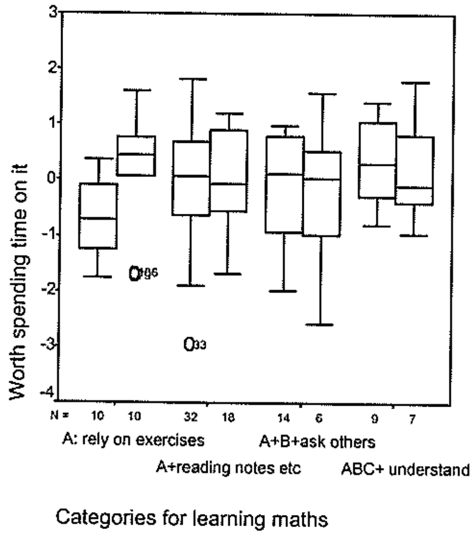

Figure 4

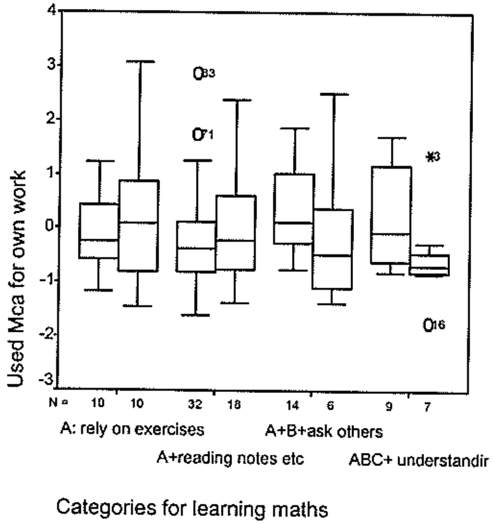

Figure 5

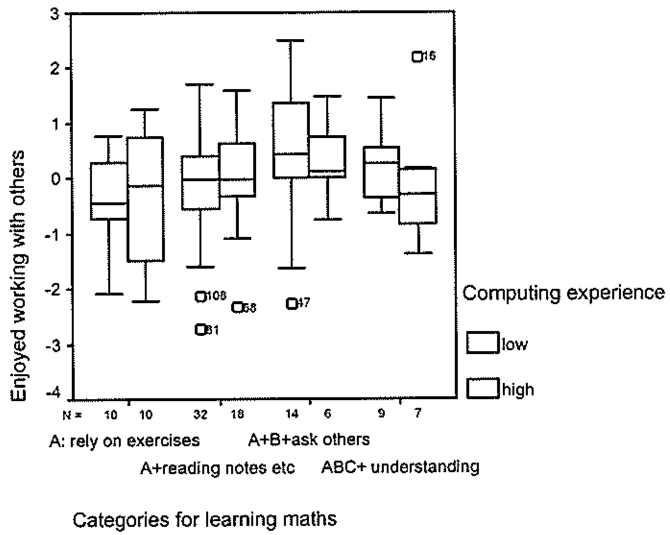

Figure 6

Figure 4, Figure 5, Figure 6 "Scores on the three components of CAS experience, reported by category of engagement in learning mathematics"

Discussion: Figure 4

We interpret the boxplots in Figure 4 to indicate that across the four categories of engagement, having a high level of computing experience seems to have a diminishing effect on the appropriation of the new tool as the level of engagement in learning increases.

Looking at category D it seems that students with a moderate to high level of engagement in their mathematical learning are able to overcome the negative effects of a low computer background in order to learn to use this new tool for their own work in the current and other subjects. Further evidence for this was found by examining the responses to the open-ended questions "Overall, how would you describe your experience with *Mathematica* in your first semester?" and "What do you think the staff could do to improve your experiences of learning Mathematics with *Mathematica?"* The students in category D with low computing background but scores on "Used for own work" that were higher than the median for category D students with high computing backgrounds all had different responses to those open-ended questions, but a common theme was an awareness of their own responsibility for their own learning. Here are samples:

> *Frustrating, yet the amount of time I spent on it gave me some insights as to how it works.*
> *... I am a firm believer that students must work things out for themselves.*
>
> *It was fun once you understood the task and worked with a partner to try and solve the problem/task.*
>
> *It was interesting, although, I would like to buy the software and try to learn its potentials at home.*
>
> *Most of the time I did it because I had to (in the initial stages of the subject), but towards the end felt I could anticipate more confidently and had just started to experiment.*
>
> (This student commented on their lack of knowledge of the syntax...) *This lack of knowledge, on the other hand, encouraged me to research on data regarding* Mathematica *and talk with my friends about maths.*

Comparing these with the comments from those students in category D and a high computing background who scored lower on "Used for own work", we find this second group more likely to complain about the nature of the tasks they were set:

> *The tutes were good, but the assignment was a* <u>*HORROR!!!*</u> [Staff should...] *Limit the no. of tutes for just inputting data directly from the sheet into Mathematica, and increase tutes where reasoning and finding calculation are needed instead of inputting data.*
>
> *It was a bit slow – you may as well have done the questions by yourself. It was useful for checking.*
>
> *Frustrating at times, but strangely satisfying at time. However, the tute work didn't involve or allow much understanding, simply copying from a page.*

The copying from a page and inputting refer to a set of tasks developed for students to use in tutorials: problems of real world relevance were presented in written form along with solutions with *Mathematica,* and students were expected to type in the solutions step by step and follow the reasoning. We know from our interviews that students who took the time to read the commentary along with the step by step solutions found that this was a rewarding experience, but many students found it tedious and time consuming.

Could it be that students with a high prior computing background and high level of engagement in mathematical learning expected to be able to pick up the new software easily and use it in a creative way, and were frustrated when the task demands prevented that? This would be an interesting issue for a follow up study.

Discussion, Figure 5

For us the most interesting feature of Figure 5 is the importance of computing background for students who have a surface approach to learning mathematics. These are the students in category A where those with a high computing background were more likely to agree that it was worth spending time on the computer algebra system. This is not surprising as the item that contributed most to the component "Worth spending time on it" was "The difficulty of the software made it almost not worthwhile *Reversed.*" We looked at responses to the open-ended questions to find out more. Students in category A with a low computing background often mentioned the need for more practical help and explanations from staff. On the other hand, students in category A with a high computing background found it interesting and useful to work with the new software, even if they needed to make a big effort to learn the syntax.

Of interest here was a group of five students in a Mathematics and Finance degree course who had low computing backgrounds and did not agree that it was worth spending time on *Mathematica*. These five students were recent school leavers who had studied mathematics at a high level at High School (four had studied 4 Unit Mathematics, the highest course, one had studied 3 Unit.) They performed well in the formal assessment components in the relevant subject in first semester. Their comments indicate a less than happy experience:

> *Personally I'm not really good at using computer programs, mathematical or otherwise so it was not a good experience.* [Staff could...] *explain more thoroughly the commands.*

> *A waste of time. Staff could increase practical help and provide more practice.*

> *Ok, not appealing, I guess I did learn something but I can't really use it to my advantage, yet.*

There may be an issue to follow up here regarding the matching of student expectations in this course in particular. Where they expecting to be working on material more directly aligned to their chosen field? Were they, as students successful with mathematics at high school using paper technologies, surprised that importance was attached to working with computers in mathematics, something they had not met before?

In Figure 6 we interpret the trends as showing that the social dimension of learning is important to students in category C, who also enjoy the interaction with others that happens when discussing a new tool. The average age of students in category C was 26, contrasting with the overall average age of 21. There was also a much higher proportion of non-recent school leavers in category C: 13 of the 20 (65%) compared with 36% overall. There did not appear to be a standout difference *within* category C when it came to High and Low computing backgrounds. Students in this category were articulate when it came to suggesting improvements that teaching staff could make. For example these comments are from students in category C with a low computing background:

> *It would be helpful if tutors were available 100% of the time during a tutorial. I did not know how to save files. Some handouts on this would be helpful. Is there a general introductory video on* Mathematica *available? If so, this would be helpful.*

> *More tutors in Maths Study Centre – More people to be able to approach with difficulties (times that lecturers/tutors are available outside class times is quite limited.)*

> *Discuss the functions more... Give feedback on assignments. I received a low mark and it was not said why.*

> *My lecturer gave to students* Mathematica *lab sheet before we started to do. It was very good for students....*

> *Produce a more comprehensive and user friendly textbook.*

> *More information is needed on all the functions and what certain output messages mean.*

These comments are from students in category C with a high computing background:

> Mathematica *I found was a difficult program to master. The tutors did not care if we didn't understand it and I always panic about* Mathematica *assignments. You always have to go out of your own time to learn the program rather than learn it in tutorial classes.*

> *Good. I can see its use as a tool in industry. We should have more of a chance to learn* <u>*with*</u> *staff aid before a major assignment...*

In trying to understand the patterns we have outlined in this data we can see a complex interplay of factors including the cultural historical origins of students' experience, the realities of course requirements (rules and division of labour) and the disjunction between school and university contexts in terms of the expected role of learners, teachers and tools used for mathematics.

It is clear that there is a disjunction between the capabilities that were associated with success at school and those leading to satisfaction in the CAS aspect of the university course. One student described the initial reaction to the new context as follows:

> *Wow! I mean something that does, integrates, this and that, you know. I'm just thinking "Well! that's it, that's the end of Maths." (S1)*

After a period of reflection the following response was made:

> *But I guess at that point I hadn't quite grasped what I do grasp now, and that's that it's just a better tool...it's the difference, you know between a bit and brace and an electric drill. (S1)*

Students in Category D with low computing background but strong in their commitment to constructing personal understanding (actions) in their mathematics learning: appear to

regard the CAS *Mathematica* as a tool for extending that search for personal meaning. On the other hand, students in Category A who have been successful rule-followers and heavily reliant on operational approaches to mathematics in the past, are frustrated by the new demands of tasks that are less firmly defined, call for more self-direction, and for which their school mathematical experience does not prepare them.

Lack of computing experience adds to the frustration of the rule followers with a history of success at school. If they are fortunate enough to have computing experience they often overcame the frustration of learning for themselves, but expected more assistance from teaching staff. The issue of the division of labour in terms of responsibility for learning is a major shift for first year university students. Many comments about the need for tutors to be more experienced with the software, and the kinds of tasks that were set, suggest that tutor expertise may also have reflected the mathematics of paper technologies. For some students the experience led to a new conception of the nature of mathematical knowledge. The quote below is illustrative:

> *They were things that I never thought at all that maths would be involved in...the building of a roller coaster or the embroidery of a design on someone's hat!*
>
> *It's a question asked by many kids "When are we ever going to use this in real life?"*
>
> *And this year I found out just that. It does get used in real life and many of the applications there are true of the real world, even if they are in the simplest form. The real world can be quite complex. (S5)*

Those older students in Category C who were seeking new and meaningful learning and who helped each other come to grips with the software had a rewarding experience. However, the experience came at the cost of more time than they thought the subject warranted as part of the usual learning contract in first year university. These people were also exchanging knowledge and ideas with their community of fellow learners and establishing informal rules of engagement in the labs.

Conclusions

Activity Theory provided an explanatory framework for interpretation for accounts by students, from different backgrounds and displaying different levels of engagement with mathematics, of their encounters with a new mathematical tool. The emergent picture is one of tensions and contradictions between the various elements in a very complex system of Activity with a long cultural history. A central issue is the epistemological misalignment between university and school teaching practices, and academic expertise, derived from a long cultural history of using paper technologies and the demands and potential of the computer algebra system. Figure 7. below shows some of the emerging contradictions.

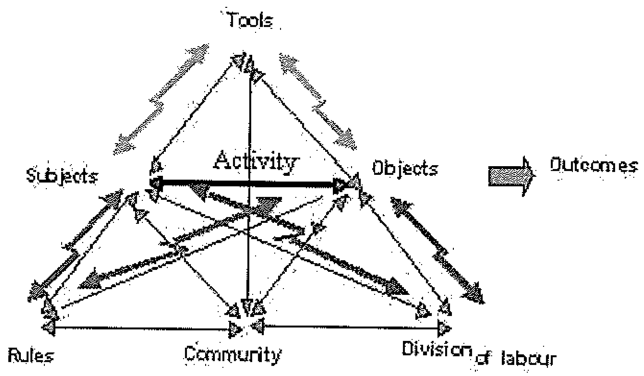

Figure 7: Contradictions emerging from a change of tool in a complex cultural practice

The contradictions involved both institutional learning cultures, conceptions of staff expertise in the discipline and also as teachers, students' cultural historical experience, and the

way that the computer algebra system is integrated into the older socio-technical Activity of mathematics education. There are emerging contradictions between:

- The new tool and the educational culture
- The objects of various participants in the system
- The institutional authority and practice of people expertise using paper technologies and the needs and learning of students using the new system.The expected roles for teachers and students and the demands of the new context

It is clear from our data that the students' experience of mathematics learning at school does not necessarily prepare them for later experiences at university using the new complex technical systems used by mathematicians in the twenty first century. Many still have little prior experience of using computers. Many have also had substantial success at school while taking an essentially operational approach to learning. The *Mathematica* tool not only automates many of students' earlier skills but also places new demands for self-directed learning on them. Thus the new system changes the capabilities that are needed for success and removes the advantage of those operational capabilities that were the basis of former success in learning mathematics.

It is clear that the university context itself is also emerging from a long history of using paper technologies and transmission models of learning that have resulted in patterns of expectations, and staff expertise, that are not geared to deep engagement by students in achieving personally meaningful learning using complex technical systems.

One might speculate that the gap, described here, between experiences using paper technologies and later experiences using complex technical systems provides an insight to the many new stresses experienced by people in post industrial work places at this point in history.

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Introduction

Over the last decade there have been numerous applications of sociocultural Activity Theory to research areas related to Information Systems (IS). These include work in organisations, computer supported cooperative work (CSCW) and human-computer interaction (HCI). Recently the field of AT applications has been extended to a wider variety of IS-related disciplines such as knowledge management, usability testing, computer-mediated communication and web-based marketing. The appeal of AT to the scholars who explore the area of computer-mediated human practices can be explained by its broad view of the human psyche and behaviour and its well-structured categories of analysis. The AT recognition of people as being embedded in their socio-cultural context allow researchers to undertake a deeper view of human practices in its relation to information and communication technologies.

The rapidly increasing amount of research based on the principals of Activity Theory has a reciprocal effect on the theory itself, expanding its horizons and influencing the ways that it progresses. The complex texture of activity theory has been further explored and enriched by relating its concepts and constructs to those of other modern theories.

This book is the third volume in the series dealing with the use of the Vygotskian based Activity Theory in IS-related research. The papers, included in this series, have been written by participants of a sequence of annual workshops on Activity theory and Information Systems, held at the University of Wollongong since 1995. As can be seen from the contributors to the series, these workshops have attracted a core group of participants from a variety of institutions across Australia and overseas.

The first volume of the series provided some basic concepts and introduced the reader to the position occupied in psychology by Activity Theory. It also provides some examples of its application in an organisational context and concludes with an annotated bibliography to assist new researchers beginning in this area to understand the background and seminal works on the topic.

The second volume continues with the theory in greater depth and introduces the reader to wider applications of its contextual aspects such as computer-mediated work, interface design and executive information systems. It also contains an interesting paper by Yrjo Engestrom exploring the concept of social capital using Activity Theory as a basis for the analysis.

This volume contains papers in part 1 which delve deeper into specifics of the theory, such as Vygotsky's zone of proximal development, its application to technology and a suggested evolutionary path for possible new directions. Part 2 is the application of AT to Knowledge Management while part 3 applies the theory to usability and the Internet. Part 4 contains papers on the use of AT in education, emotions and thinking and information seeking. The final part examines AT and its relationship to business process modelling.