Burke, P. F., Kearney, M., Schuck, S., & Aubusson, P. (2021). Improving mobile learning in secondary mathematics and science: Listening to students. *Journal of Computer Assisted Learning*, 1–15. https://doi.org/10.1111/jcal.12596

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Improving mobile learning in secondary school mathematics and science: Listening to students

Abstract

Background: Mobile learning studies often focus on teachers' perspectives. This study instead considers students' experiences of learning with mobile devices (i.e., m-learning) in secondary school mathematics and science.

Objectives: The research aims to describe the m-learning experiences of secondary mathematics and science students, and to determine the extent to which distinctive pedagogical dimensions impact students' perceived learning.

Methods: A survey instrument using the iPAC mobile pedagogical framework as a theoretical lens is developed and validated. This framework highlights three pedagogical dimensions: personalisation, authenticity, and collaboration. Structural equation modelling is used to investigate how each dimension predicts students' perceived improvement in learning, whilst accounting for usage context, among a sample of students in schools where mobile devices are used extensively.

Results and Conclusions: Students were in agreement that personalisation was a characteristic of their m-learning experiences, but authentic and collaborative learning were not as strongly featured. M-learning activities fostering personalisation were most important for improving perceived learning; authenticity and collaboration were also significant, but no differences in perceived learning improvement due to location were found. Authentic m-learning and perceived improvement in learning with mobile devices were significantly higher in science than mathematics subjects.

Implications: When teachers design m-learning tasks that enhance personalisation, collaboration, and authenticity, students are predicted to perceive improvements in their learning. The findings suggest that teachers should consider designing technology-enhanced tasks that improve students' experiences of collaborative and authentic learning, particularly in mathematics for greatest gains in students' perceived improvement in learning.

Keywords: cooperative/collaborative learning; improving classroom teaching; mobile learning; pedagogical issues; secondary education; iPAC.

Introduction

Learning with mobile devices (or m-learning) appears to have great potential for enhancing learning, but currently this potential is under-realised (Bartholomew & Reeve, 2018; Haßler, Major, & Hennessy, 2016; Thomas & Munoz, 2016). While use of mobile devices is ubiquitous in workplaces and for personal use, their educational use tends to be limited. This article provides valuable insights into the potential of m-learning in the context of maths and science education, from the perspective of secondary school students. This study was part of a larger project investigating m-learning in Australia. In particular, the project focused on interrogating teaching and learning with mobile devices, as recommended by other technology-enhanced learning researchers (Nouri, Spikol, & Cerratto-Pargman, 2016; Wright & Parchoma, 2011). For example, Nouri et al. (2016) recommend that the emphasis in m-learning research should avoid a technical focus and instead focus on investigating learning task designs and experiences, and how devices might be used to support pedagogy (mobile pedagogy).

Much of the literature on the use of mobile technologies to support learning (m-learning) has focused on teachers' perspectives (Bourke & Loveridge, 2016; Uzunboylu & Ozdamli, 2011) or has sought insights from experts and other stakeholders in educational technology (Volman, 2005). Further, whilst researchers reviewing the literature have been able to identify a number of technical factors of mobile devices that contribute to learning, it has been reported to be more difficult to draw out pedagogical factors because of the limited scope and duration of studies in the field (Haßler, Major, & Hennessy, 2016). Fewer studies offer the perspective of students, themselves a critical stakeholder in m-learning pedagogy. Even when teachers consider student perspectives, they tend to interpret student voice using their own frames of reference (Bourke & Loveridge, 2016). Education research emphasising student voice and using objective measures is an important means of understanding how students view their learning experiences and can lead to critical insights that support students' needs and improve outcomes (Cook-Sather, 2014; Mockler & Groundwater-Smith, 2015).

Where students' perspectives are reported in m-learning studies, they generally concern generic aspects of m-learning related to usability, access, engagement, motivation, and potential risks, or explore their experiences of mobile pedagogy in a limited way (e.g., Hodge, Robertson, & Sargisson, 2017; Lai, Hwang, Liang, & Tsai, 2016; Lindberg Ola, 2017). Researchers often consider many of these experiences in the context of evaluating an intervention (e.g., Daher, 2017; DeWitt, Siraj, & Alias, 2014). In the study reported here, we investigated student perspectives related to their everyday experiences of m-learning.

Central to research discussed in this article, is the iPAC mobile pedagogical framework (Burden & Kearney, 2018; Kearney et al., 2012; Kearney et al., 2019; Kearney, Burden, Schuck, Burke, & Aubusson, 2020), which was developed to capture signature pedagogies adopted when using mobile technologies for teaching. The framework is underpinned by socio-cultural theory. This theory acknowledges that learning is situated and social in nature, is developed through social interactions and conversations between people (Vygotsky, 1978), and is mediated by tools such as mobile devices and applications ('apps') (Pachler, Bachmair & Cook, 2013). It suggests a two-way dynamic between tools and their users: learning is affected by these tools, and reciprocally, the learning tools are modified by the ways in which they are used for learning (Glassman, 2001; Wertsch, 1991).

The iPAC Framework was developed by the authors (Kearney et al., 2012), and is based on the key aspects of socio-cultural theory, discussed above. The framework highlights three socio-cultural features of m-learning: personalisation (dealing with learner agency and customisation); authenticity (a concept concerning relevance and meaningful learning with respect to context and task); and collaboration (which considers aspects of peer learning with a focus on conversation and co-creation). These key concepts (personalisation, authenticity and collaboration) are strongly aligned with socio-cultural theory, highlighting as they do, the mediation of the individual in the learning (personalisation), the situated nature of learning expressed as authentic learning and the social nature of learning, identified in the collaborative dimension of the iPAC Framework. The personalisation feature has strong implications for ownership and autonomous learning (Scanlon et al., 2011); the authenticity feature highlights opportunities for participatory, situated learning; and the collaboration feature captures the possibilities of m-learning for connection and sharing (Kearney, Burden, & Schuck, 2020). The framework also highlights the learner context, dealing with questions of the time, place and scheduling of learning, and its influence on students' experiences of the three iPAC pedagogies. More detail about the iPAC Framework, its origins and dimensions and the underlying socio-cultural theory can be found at www.ipacmobilepedagogy.com.

The purpose of our research was to investigate secondary school students' m-learning experiences in mathematics and science, specifically their experiences of the three distinct mobile pedagogies highlighted in our iPAC framework. We investigate the students' perceived level of improvement in learning with respect to these three pedagogies and interrogate differences across secondary maths and science. We focus on the role that students' m-learning experiences have on their perceived improvement in learning (PIL) and account for the role that context has on PIL.

We focus on the science and mathematics disciplines because effective science and mathematics education is a central aspiration for most countries. There is strong political imperative in Australia and many other countries to improve mathematics and science education in order to drive economic growth and to better prepare students for future job markets (e.g., Office of the Chief Scientist, 2014, 2020). Therefore, investigating the role of m-learning in mathematics and science education is a worthy focus for study. Student views of mathematics and science m-learning activities are critical to informing the development of mobile pedagogy and the quality of education in these disciplines in the future.

This study is significant in a number of ways. First, we use the socio-cultural lens of the iPAC Framework to examine and understand secondary students' perspectives of specific pedagogies for m-learning. Second, we focus on key areas of mathematics and science. Thirdly, we offer a robust new instrument to evaluate m-learning pedagogies from students' perspectives. The research questions guiding the study were:

1. What are the m-learning pedagogical experiences in mathematics and science of secondary students in schools where mobile devices are used extensively?
2. How do these experiences relate to these students' views of their learning?

Literature Review

Mobile learning in mathematics and science education

As mobile technologies have become ubiquitous in society and more prevalent in education, several reviews of m-learning studies have been published. Systematic reviews of research conducted on m-learning in P/K–12 education over the last decade have consistently revealed that science has been the subject most often studied (e.g., Crompton, Burke, & Gregory, 2017; Crompton, Burke, Gregory, & Gräbe, 2016; Lui, Kuhn, Acosta, Niño-Soto, Quintana, & Slotta, 2014; Wu, Wu, Chen, Kao, Lin, & Huang, 2012).

Much research conducted on m-learning in secondary mathematics and science has focused on the development of apps (Zydney & Warner, 2016) or the effectiveness and implementation of apps (Bano et al., 2018). Other reviews (Fu & Hwang, 2018; Suárez, Specht, Prinsen, Kalz, & Ternier, 2018) have focused on use of mobile devices to support inquiry-based learning and collaborative learning. These two pedagogical approaches are among the three principal approaches (inquiry-based learning, collaboration, and realistic learning) identified by Bano et al. (2018) in their review of mathematics and science studies. The literature review conducted by Suárez et al. (2018) examined the extent to which the use of mobile technologies supported learners' agency in inquiry-based learning. They noted that mobile technologies provided students with opportunities for more personalised and autonomous seamless experiences across learning contexts. Frohberg, Göth, and Schwabe's (2009) review focuses on a task model of m-learning (Taylor et al. 2006), which highlights the governance of technological and semiotic rules for various task dimensions, such as control, context and communication, as critical components to understanding how revised knowledge and skills take place. On the other hand, Roschelle (2003) highlights the complementary value of the learning activities that occur in designing and debriefing phases not mediated by the mobile technology where students and teachers compare, elaborate, explain, critique and argue. Nonetheless, better designed technologies also encourage and facilitate such collaborative activities online (DeWitt et al., 2014; Frohberg et al., 2009; Wertsch, 1991).

Kearney, Burden, Schuck, Burke, and Aubusson (2020) captured a snapshot of Australian mathematics and science teachers' contemporary use of mobile pedagogies. The study highlighted nuanced similarities and differences between mathematics and science teachers' views of their current practices. The main similarity between the mathematics and science teachers' m-learning practices was their choice of traditional, formal settings for their students' learning, with minimal consideration given to semi-formal and informal learning spaces. The authors also find that science teachers reported that they more frequently adopted authentic learning opportunities when designing their m-learning activities. Mathematics teachers revealed a preference for didactic, drill and practice approaches, while science teachers preferred inquiry and project-based learning approaches. Both groups of teachers restricted their students' use of mobile devices to communicate and exchange information online with peers. Students' self-pacing was a feature of both groups, though other aspects of personalisation were less evident. For example, both groups of teachers perceived that their students had little control over their choice of apps and lacked opportunities to customise settings to support their own mathematics and science learning.

Students' perspectives of mobile learning

M-learning studies that have elicited students' perspectives to inform findings have typically focused on general issues related to usability, access, engagement, motivation, and potential harm and pitfalls. Several studies, including those noted within the reviews mentioned in the previous section, report on students' opinions about the use of mobile devices for learning. Lindberg Ola (2017) found a marked discrepancy between upper secondary Swedish students' in-school and out-of-school use of smartphones, possibly because their use of smartphones at school was restricted and because ICT infrastructure in Swedish schools was a generation older than what students used out of school. They found discrepancies between teachers' and students' views about the educational potential of smartphones. Lai et al. (2016) also explored differences between the m-learning preferences of high school teachers and students in Taiwan. The study revealed that the teachers tended to focus more on technical issues, while the students mainly cared about the adaptiveness and richness of digital content accessible through their devices. Indeed, Voogt et al.'s (2013) review concludes that teachers need to be supported in their professional development, to not only learn basic skills relating to technologies, but learn how to effectively use them in pedagogical settings and how to integrate their use into the curriculum.

A study by Hodge et al. (2017) suggested that students should be more frequently included in discussions about m-learning practices. Their focus groups with early adolescent participants revealed that mobile device use restrictions, student control over the technology, and connectivity were the students' main concerns. The students stated that access to tools with a primarily educational purpose was often impeded by security measures; however, they also acknowledged potential negative effects of using mobile devices, especially distraction from learning, as has been reported in other studies (e.g., Bartholomew & Reeve, 2018; Thomas & Munoz, 2016).

Views of m-learning have also been elicited from secondary Greek students (Nikolopoulou, 2018). These students believed that mobile devices were an incentive for learning and that they helped them to understand concepts and to complete school assignments. The higher the grade age group, the more positive were students' opinions. Students regarded m-learning as useful because it enabled them to access information quickly, at a time and place of their choice, and on a device of their choice. Mobile network technology, ideally with access 24 hours a day to subject matter at home or school, as well as linking devices to the school intranet, also fosters students' ability to work and study in a self-directed manner, when and where they want (Volman, 2005). Indeed, Walker (2013), who sought students' perspectives of using mobile devices for learning, found that students were using many of the features of their devices and had often found creative ways to employ these features in their schoolwork, both at home and at school. The students believed that mobile devices helped with their learning and that they were convenient and useful, but they also acknowledged their potential for disruption and for harm. As Roschelle (2003) explains, connectivity can come at the expense of a student's attention to the teacher, which they describe as "a teachers' most precious commodity" (p. 265). A focus on students' views of their m-learning experiences in mathematics and science specifically has been reported in a number of studies and these are discussed in the next section.

Students' perspectives of mobile learning in science and mathematics education

M-learning studies in science and mathematics education have drawn on students' perspectives to mainly focus on their views of engagement and affective aspects such as confidence levels, rather than pedagogy (e.g., Daher, 2017; Zhai, Zhang & Li, 2018). A small number of studies have focused on students' views of teaching and learning with mobile devices but most of these studies were evaluating interventions rather than naturalistic studies of students' m-learning experiences (e.g., Çetinkaya, 2019; Chang, Hsu, Wu & Tsai, 2018).

In science education, many m-learning studies have focused on students' views of inquiry-based learning interventions (e.g. DeWitt et al., 2014; Hochberg, Kuhn & Müller, 2018; Wallace & Bodzin, 2017), often with a focus on affective outcomes. DeWitt et al. (2014) reported on a collaborative m-learning science module, which provided an opportunity for learning science through inquiry approaches, and allowed learners to participate in discussions while solving problems. The researchers collected data from secondary science students in surveys and interviews and triangulated the results with students' online communications. The findings showed that the students were motivated and interested in learning and that they believed their science understanding improved. Examples of authentic learning assisted by the presence of mobile learning devices have also been presented in the literature, particularly in the context of science education. For example, a case study by Khoo and Otrel-Cass (2017) investigated the ways that secondary students adopted mobile phones to support authentic science inquiry. The researchers collected data from students through interviews, survey, classroom observations, and student work samples. The results showed that, when mobile phones were part of the classroom culture, they encouraged practices such as capturing learning experiences, reviewing questions, and pursuing new lines of investigation. This supported students' scientific inquiry, helped them to think like scientists and enabled them to share their learning beyond the classroom. Wallace and Bodzin (2017) studied a group of 9th grade students who participated in a citizen science project where they studied climate change and used mobile devices to observe and report cyclical data. Results showed that this approach had a significant impact on the students' attitudes towards citizen science identity as well as towards careers in STEM areas. Hochberg, Kuhn, and Müller (2018) investigated upper secondary physics students' use of smartphones' built-in sensors to investigate pendulum mechanics. They found that the use of smartphones as experimental tools significantly raised students' interest in their physics classes and their curiosity about the content of the experiments. Wu, Hwang, and Tsai (2013) developed context-aware ubiquitous learning activities to help senior high school geoscience students recognise and differentiate rocks in a laboratory. Their study collected the students' feedback in terms of "perceived usefulness" and "perceived ease of use" of the learning system. The students in the experimental group that used the m-learning system revealed better learning attitudes than those in the control group.

Other science education studies have focused on interventions involving the use of augmented reality (AR) apps, drawing on data collected from students to show benefits for observation, decision-making, and other science processing skills. For example, Nielsen, Brandt & Swensen (2018) investigated the use of AR resources with lower secondary science students. Participants reported on positive learning benefits, including a sense of immersion in the science phenomena and being able to "see the invisible". Using AR technologies, Chang et al. (2018) engaged senior high school students in decision-making activities where students had to investigate pollution in their school grounds in an imaginary nuclear radiation accident. Following the AR-based activities, students reported lower levels of perceived complexity in relation to decision-making about the issue. More recently, Liu et al. (2020) found that science students allocated to learn via AR technology reported better learning outcomes and lower levels of perceived task difficulty than those allocated to a condition using 3D technology or traditional delivery methods.

A few science education m-learning studies have been more naturalistic in their approach, eliciting students views of their general experiences learning with mobile devices

(Zhai et al., 2018); Zhai, Li & Chen, 2019). Again, affective outcomes have been a strong focus. Zhai et al. (2018) studied the impact of high school students' mobile technology use on their interest in physics and their learning performance. The students perceived their mostly autonomous use of mobile devices during and after school as very effective for their physics learning. The frequency of their mobile device use positively influenced their interest and physics learning achievement. While Zhai et al. (2019) found that the student-controlled functions on their mobile devices significantly predicted the students' physics achievement and interest.

In mathematics education, there has been a similar emphasis on interventionist m-learning studies. Larkin and Calder (2016) and Daher (2017) highlighted the connectivity affordances of mobile devices that offer students more flexibility to work collaboratively in their mathematics learning. In Daher's (2017) study, middle school students participated in outdoor activities using mobile phones to explore the mathematics of real-life phenomena. The students reported that having freedom and autonomy to carry out the activities and sharing ideas between peers helped them to explore the phenomena mathematically and to build models to aid their understanding. The researcher found benefits for students' motivation, self-efficacy, confidence, content, enjoyment, and empowerment. Çetinkaya (2019) conducted a study with secondary school mathematics students to investigate problem-based learning with mobile-based applications. The students reported positive opinions about the m-learning environment and the problem-based teaching process. Bray and Tangney (2016) found an improvement in secondary students' attitudes, behaviour, and confidence resulting from a mathematics m-learning intervention. Student data showed increased student engagement with, and confidence in, mathematics. The authors also reported that interesting, real-world mathematics problems were motivating to student participants, and helped them to develop a sense of autonomy and ownership of their learning.

Some Maths education studies have focused on eliciting students' views of their typical m-learning experiences but again, the focus is typically on affective aspects of learning. For instance, Fabian, Topping and Barron (2016) conducted a systematic review of studies utilising mobile devices for mathematics to investigate student perceptions and attitudes, student achievement, and student engagement. Their review noted that student attitudes to mobile device use were mostly positive with the advantages of using mobile technologies mentioned by students including: ease of use, lack of cost, being easily accessible, being fast and secure in communication, learning anytime anywhere, as well as resource and material sharing.

In summary, although there are numerous m-learning studies of science and mathematics students' views of engagement and affective aspects, such as confidence and motivation, only a few studies have focused on their perceptions of pedagogical aspects. Many studies evaluate an intervention, focusing on students' views of generic aspects of m-learning such as access, ease of use, convenience, usefulness, frequency of use, settings, potential harm and pitfalls (e.g., distraction) and school policies. Additionally, there are some m-learning studies involving students' views of their potential or hypothetical use of mobile devices for learning, rather than investigating their actual experiences. While the study reported in this paper ascertains students' views of generic characteristics of m-learning such as settings and device ownership, the main focus is on science and mathematics students' experiences of signature mobile pedagogies (personalisation, authenticity, and collaboration) and their perceived influence on students' learning. To investigate student views, a survey was developed and distributed to a sample of secondary school students. The next section describes respondents, the design of the survey, data collection, and analysis.

Study Design

Sample

The larger study, of which this student survey was part, investigated the experiences of students and teachers across Australian secondary schools. Four schools were recommended to the researchers by various school leaders based on the schools' reputations for extensive and effective integration of m-learning approaches in secondary maths and science education. The school leadership teams in each school nominated teachers and student cohorts for participation in the first part of the study. All four schools employed a Bring Your Own Device (BYOD) policy for their students. Three schools were located in the Australian state of New South Wales, and one in the Australian state of Victoria. The schools comprised three government schools and one non-government school. Three schools were co-educational and one was an all-girls school. Schools disseminated the online survey to their students in Years 7 (aged 12 to 13 years old) to 10 (aged 15 to 16 years old). Participation was voluntary. The survey was anonymous and took approximately 10 minutes to complete. In total, respondents to the student survey comprised 928 students from these four schools. Students were asked to comment on their typical m-learning in either mathematics or science.

Instrument Development

The student survey instrument was developed over several iterations. First, the researchers compiled a list of potential items for inclusion for each iPAC construct based on previous literature. Second, a series of initial formal and informal discussions took place about m-learning pedagogies with other researchers and experts in m-learning, as well as pre-service and in-service teachers to supplement the list further. Face validity and construct validity of the items related to the iPAC Framework was achieved through frequent discussions amongst the authors, two other local professors with expertise in the field and an international m-learning scholar who was a critical friend of the project. These experts considered and provided feedback on how well items aligned with the framework's dimensions and the underlying socio-cultural theory. The items were shared with pre-service and in-service teachers who discussed these with their school students and provided feedback on the examples used and comprehension of items. Finally, the research proceeded to a small pilot with one school, before releasing the survey to the four participating schools.

In the final version of the survey, each student respondent was initially asked to select a discipline area of either mathematics or science to consider as his or her chosen context when responding to items. The survey comprised of eight initial background items asking for information about a range of aspects, such as confidence levels with mobile technology, device ownership, m-learning locations, and favourite apps. These were followed by 19 iPAC items that sought information about students' typical experiences with mobile pedagogies in their chosen discipline. There were seven items relating to personalisation, six items relating to authenticity, and six items focused on collaboration. The chosen context (science or mathematics) was subsequently piped through by the survey software system to be included in these iPAC survey items. For example, the stem for all these items was: "When I use a mobile device to learn school <maths/science, inserted according to a student's initial choice>, I use it to: …". An example of an authenticity item was "... I use it to: work more like an expert". Students responded using a five-point scale ranging from *never* to *always*. The survey concluded with six items, with a seven-point scale ranging from *strongly agree* to *strongly disagree*, asking students about perceptions of their overall experiences learning science or mathematics with a mobile device. A version of this survey for students is available on the [details removed for blind review] website ([website removed for blind review]).

Analysis and Results

Respondent Profiles

In total, 928 students provided responses. A number of students failed to complete the survey either because they did not qualify (e.g., seven percent had never used an m-learning device), offered invalid responses based on attention checks (e.g., invariant responses to reverse coded items), and/or were removed based on being too quick in completing the survey (the median responses time was 11 minutes). Following cleaning, 879 valid responses were used for analysis. The descriptive statistics of the sample are provided in Table 1.

Insert Table 1 about here

The majority of students surveyed attended government schools (95%), with 65% at co-educational institutions. All students were completing studies in secondary school, with 28% in Year 7, 21% in Year 8, 31% in Year 9 and the remaining 20% in Year 10.

When students were asked to nominate the one mobile device that was used by them most often to help them learn in school, the majority of students nominated a tablet (48%), followed by a smartphone (20%), laptop (17%), or iPod touch (2%); the remaining 13% were using another unspecified device. The m-learning devices being used were predominantly owned by the students themselves (90%), with seven percent using devices owned by the school. Of those using school devices, 12% were permitted only to use these devices whilst at school.

Students were asked about where they were using their mobile devices to learn mathematics or science. The majority indicated that they were using mobile devices, often or always, for learning in the classroom (54.9%), but even more were using the devices, often or always, for learning at home (69.4%). In contrast, the majority of students indicated that they were never or rarely using mobiles for learning on excursions (67.8%), at other locations, for example, coffee shops, travel to school, and shopping centres (57.9%), or at school outside the classroom (55.5%).

Students expressed a strong confidence in using mobile devices, with 87% agreeing that they were confident in using such devices, of which 62% noted that they were very confident. Only two percent of students indicated that they were not confident in using a mobile device. When asked about their usage of mobile devices in their everyday lives (i.e., when not using a device for schoolwork), 84% of students indicated that they often did so; only five percent indicated that they never or seldom did so.

These sample descriptions were similar for students, irrespective of whether they were studying mathematics (65% of respondents) or science (35% of respondents). The only exception was with respect to the most frequently used m-learning device. Specifically, 63% of students referencing science in their responses were using a tablet, as opposed to 34% of students reporting their experiences in mathematics. Twenty-six per cent of mathematics students referred to experiences using a smartphone, whilst only 5% of science students did so. None of these differences significantly affected responses in relation to the independent variables describing m-learning (i.e., personalisation, authenticity, collaboration), context of location (e.g., outside the classroom) or dependent variable (i.e., perceived improvement in learning) considered in the structural equation model discussed below.

Independent and Dependent Variables

Based on the iPAC Framework, three measures were considered as being potentially predictive of perceived improvement of m-learning from a student's perspective, namely personalisation, authenticity, and collaboration. A fourth independent variable, location, was also considered with respect to the main place in which m-learning was experienced (e.g., inside classroom, on school grounds, excursions, at home).

Our chosen dependent variable was students' perceived improvement in learning, rather than other aspects of m-learning that have been considered in the literature, such as overall enjoyment or attitudinal outcomes, distractions or concerns about security.

Measures and Evaluation of Reliability and Validity

A combination of exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) was performed using covariance-based modelling including all scale items for evaluation. CFA was performed using principal components analysis, initially with oblimax rotation, with the final reported results using varimax rotation (see Table 2) (Kaiser, 1958). All models showed the presence of five distinct underlying constructs consistent with our structural model (i.e., personalisation, authenticity, collaboration, location, perceived improvement in learning). Each item clearly loaded onto each construct as a reflective measure of the corresponding latent dimension as expected in both the EFA and CFA analyses. All factor loadings were significant at the .01 level and exceeded the benchmark of 0.707 (Hair, Black, Babin, & Anderson, 2009). In turn, the resulting Average Variance Extracted (AVE) for each construct exceeded 0.5 to establish convergent validity (Fornell & Larcker, 1981). With respect to reliability, Composite Reliabilities and Cronbach Alpha's (CA's) exceeded the benchmark of 0.7 for each measure (Fornell & Larcker, 1981; Nunnaly, 1978; Raykov, 1997) with CA's equal to .807, .759, .759, .832, and .872 for personalisation, authenticity, collaboration, location, and perceived improvement in learning, respectively. Discriminant validity was established, as the squared correlation between any two items was less than their respective AVEs (Fornell & Larcker, 1981). As stated above, all items loaded onto their respective focal construct without any concerns about cross-loading (Chin, 1998), with the maximum cross-loading being 0.313 in the final CFA. The Variance Inflation Factors (VIF) for the inner components of the structural model were less than three and below both the recommended thresholds of 5 (Kline, 1998) and 3.3 (Kock & Lynn, 2012) indicating that our findings are not affected by excessive levels of multicollinearity.

Insert Table 2 about here

With respect to each underlying construct, the mean scores show that students across both cohorts are experiencing m-learning that is characterised by high levels of personalisation, with an average factor score that is significantly higher than the mid-point of the five-point scale (M=3.35; SD=1.24; $p < .01$). In other words, students agreed that they used mobile technologies that allowed them to choose the place where they could complete schoolwork (M=3.19; SD=1.30), the time to do so (M=3.56; SD=1.30), and the way in which they wished to do so (M=3.30; SD=1.23), with each of these underlying items being significant.

With respect to authenticity, students disagreed that they were using m-learning in a way that promoted authentic experiences. The mean factor score for the authenticity construct across both science and mathematics cohorts combined was significantly below neutral, indicating this level of disagreement was significant (M=2.29; SD=1.16; $p < .01$). Each of the five items used to construct this reflective measure were, on average, indicative of this disagreement (see Table 2).

Similarly, students reported that their m-learning task experiences were not highly collaborative. In particular, the mean factor score (M=2.28; SD=1.27) was significantly below the neutral point ($p < .001$), as were the mean scores for the underlying reflective measures, including m-learning that involved making digital content together with friends (Item C1: M=2.28; M=1.27), exchanging content with others online (Item C2: M=2.25;

SD=1.37), and sharing and comparing content generated on their devices with others (Item C3: M=2.02; SD=1.17).

Students were also asked about their use of mobile devices for learning that occurred outside of the classroom. This was found to be significantly low across all measures with students reporting that m-learning did not occur outside of the classroom, whether at school (M=2.38; SD=1.25), on excursions (M=2.17; SD=1.22), or in other places such as while commuting or in coffee shops (M=2.43; 1.43). Taken together, the average factor score was significantly lower than the neutral point leading to the conclusions that, on average, students were not experiencing m-learning outside classroom locations (M=2.38; SD=1.30; $p < .001$).

Finally, the dependent variable in the model, perceived improvement in learning (PIL), captured whether students perceived their learning to have improved (Item PIL1), whether using mobile devices helped them to understand concepts in the subject area of mathematics or science (Item PIL2), and whether such devices helped them to practise their skills (Item PIL3). Overall, the reflective measures combined into the PIL construct indicated that the mean factor score was significantly high (M=4.90; SD=1.62; $p < .0001$). That is, students perceived that, on average, their learning had significantly improved as a result of using mobile devices in mathematics or science.

Comparison of Mathematics and Science

The latent constructs and the corresponding measurement items were used to compare students' reported m-learning experiences in mathematics with students' reported m-learning experiences in science. The respective groups' means and standard deviations for each item and latent scores are reported in Table 3. In addition, the comparisons of means were formally tested using an independent samples t-test with the results reported in the final columns of Table 2.

Insert Table 3 about here

The results indicate that both mathematics and science student cohorts were in agreement that they were experiencing personalised m-learning, but these experiences were not significantly different across the two cohorts (Mdiff=-0.106; SE=.087; p = .2222). Similarly, both groups agreed, on average, that their m-learning experiences were not authentic (M_M = 2.19; M_S=2.48). However, the experiences of science students were significantly more authentic compared to the mathematics students' experiences (Mdiff=-.286; SE=.082; $p < .0001$). Likewise, both groups reported significantly low levels of m-learning that encouraged collaborative learning experiences (M_M = 2.29; M_S=2.26). Further, the levels of collaboration were not significantly different in the two cohorts (Mdiff=.036; SE=.088; p = .686).

At the individual item level, however, the findings were somewhat mixed. Although relatively low, science students were significantly more likely to report that they were using their devices to make digital content with friends as compared to mathematics students (Item C1: M_M = 2.52; M_S=2.29; Mdiff=-0.174; $p < .05$). In contrast, mathematics students reported significantly higher levels of agreement that they were using their mobile devices to exchange something with others online as compared to science students (Item C2: M_M = 2.32; M_S=2.12; Mdiff=0.203; $p < .05$). Despite these slight differences, the results indicate that both groups were generally not using mobiles in collaborative ways.

The results can also be considered with respect to differences across mathematics and science subjects in terms of the frequency with which m-learning takes place outside of the classroom setting. As noted above, levels of outside classroom use were significantly low overall (M=2.38), but these lower levels were significantly more likely for students reporting on their science experiences than for those reporting on their mathematics experiences (M_M =2.44; M_S=2.26; Mdiff=0.171; $p < .10$). When compared to science students, mathematics students were more likely to use their mobile devices whilst on excursions (Item O2: Mdiff=0.250; $p < .01$) and in other places (Item O3: Mdiff=0.194; $p < .05$). The differences in use of m-learning occurring outside of the classroom, but whilst still at school, were negligible (Item O1: Mdiff=0.067; $p = .443$).

Finally, the survey captured students' perceptions of their overall m-learning experiences. Compared to mathematics students, science students were significantly more likely to report that their learning had improved as a result of using mobile devices (M_M =4.77; M_S=5.13; Mdiff=-0.364; $p < .0001$). These significant differences were also found in relation to all three underlying measurement items relating to aspects of overall improved learning (Item PIL1), the understanding of concepts (Item PIL2), and encouragement of students to practise skills (Item PIL3).

Structural Model Evaluation and Results

The aforementioned measures were included into a structural model to assess whether the iPAC dimensions acted as antecedents to predict improvements in students' perceived improvements in learning, whilst also considering the role of the location in which devices were being used. A structural equation model was estimated using a covariance-based approach (Hair et al., 2009). The model results and estimated standardised path coefficients are presented in Figure 1.

Insert Figure 1 about here

The model was estimated using a covariance-variance based approach using all 878 observations. The comparative fit index (CFI) was .973 (Bentler, 1990; Bentler & Bonett,

1980) and the Tucker-Lewis Index (TLI) was .964 (Tucker & Lewis, 1973), indicating acceptable levels of incremental fit (Hu & Bentler, 1999). The root-mean square error of approximation (RMSEA) was significantly below the suggested benchmark of .05 (RMSEA=.038; $p < .01$) (Steiger & Lind, 1980), indicating acceptable model fit (Browne & Cudeck, 1992; Steiger, 1989). All parameter estimates of path relationships were significant at the .01 level. Taken together, the results indicate that all iPAC dimensions and the location of the task are significant independent variables in predicting the dependent variable, perceived improvements in learning (PIL).

The model results and standardised path coefficients presented in Figure 1 show that students who perceive their m-learning experiences to be characterised by personalisation (β=.345), authenticity (β=.185), and collaboration (β=.098) are more likely to experience perceived improvements in their learning for a particular subject, with all these effects significant ($p < .001$). Comparatively, the mean path coefficient estimates indicate that varying personalisation in students' m-learning experience is predicted to have the largest effect on perceived improved learning for students in secondary mathematics and science.

The results also show that students who are engaged with mobile technologies outside the classroom are significantly less likely to report a perceived improvement in their learning with mobile technologies (β=-0.083; $p < .05$). These results and their implications are discussed in the next section.

Discussion

This article provides a voice for secondary students by drawing on their experiences and perceptions of m-learning in mathematics and science. The key dimensions of the iPAC Framework were shown to enhance students' perceptions of improved learning. Location of learning was not found to contribute to improvement in learning. There were significant differences in students' mathematics and science m-learning experiences. Finally, the survey used to measure students' perceptions was validated in this study.

The model confirms a link between the three independent variables of the iPAC framework, namely (students' experiences of) personalisation, collaboration and authenticity, and their significant impact on student's perceived improvements in their learning (PIL). The most significant of these dimensions was personalisation, followed by collaboration and authenticity. The implications of these results are that when teachers are able to design m-learning tasks that foster greater aspects of personalisation, collaboration, and authenticity, students are predicted to perceive greater improvements in their learning. As a result, the findings encourage teachers to be more selective about the type of tasks and apps that are chosen for students to use as part of their m-learning activities. For example, teachers are encouraged to select activities that provide greater forms of personalised feedback to students, encourage sharing and collaboration across devices and in contexts that provide more authentic and relevant opportunities for learning. Similarly, m-learning tasks and apps that do not provide feedback to students, those that isolate students in their learning activities requiring them to work on their own, or do so in ways that are not well connected to real-life settings and applications, are likely to be associated with student perceptions that their learning is not improved by mobile connected activities.

The findings of this study also add insights to a previous study based on teachers' views elicited from a similar survey on the iPAC dimensions (Kearney, Burden, Schuck, Burke, & Aubusson, 2020). That study indicated that students were infrequently exposed to authentic m-learning tasks. Similarly, teachers generally limited students' use of m-devices for aspects of collaboration, such as exchanging information online. With regard to personalisation, only one feature, working at their own pace, was reported by teachers –

students appeared to have been given little control over the choice of apps and settings on their devices. In summary, the data reported by teachers in the previous study indicated that their students had few experiences of learning tasks that were rich in personalisation, authenticity, and collaboration. In contrast, in the current study, students reported relatively high levels of a range of features of personalisation in their m-learning. They confirmed that there was relatively little experience of authenticity and collaboration in their m-learning. Nevertheless, their perception was that their learning in secondary mathematics and science improved when mobile devices were used in ways characterised by pedagogical approaches that are more personalised, more authentic, and more collaborative.

This quantitative study of mobile pedagogy offers a contrast in results regarding the level of collaboration that may be occurring as suggested in prior intervention studies in both mathematics (e.g., Daher, 2017; Holubz, 2016) and science (e.g., DeWitt et al., 2014). Specifically, the levels reported in these intervention studies were relatively high. This contrast in findings highlights the value of measuring students' perceptions about their daily m-learning activities as opposed to measuring results in an intervention.

An interesting result concerns the location of students' m-learning activities. While it would be assumed that the mobile nature of devices would broaden the range of locations or settings in which learning took place, the results show that use was principally restricted to the classroom or home. This is consistent with the teacher survey, which indicated that tasks were predominantly designed for classrooms or homes (Kearney, Burden, Schuck, Burke, & Aubusson, 2020). This may also explain why students perceived that improved learning was more likely to occur when mobile devices were being used inside rather than outside the classroom. We could speculate that students felt that work outside of the school or home was not acknowledged as learning.

Another explanation for this result is that the devices may act as a distraction to student learning in locations outside the classroom, particularly in settings without the presence or guidance of teachers (Thomas & Munoz, 2016; Ott, Magnusson, Weilenmann, & af Segerstad, 2018). Others suggest that the classroom environment provides a space for m-learning that students consider more focused and engaging (Fabian et al., 2016). This suggestion may explain the difference in students' reported perceived m-learning inside the classroom relative to outside the classroom. Finally, two issues that may influence location of learning concern the availability of data connectivity outside of the home and school, and teachers' lack of awareness of the nature and extent of students' expertise in out-of-school technology use (e.g., Hodge et al., 2017; Sutherland et al., 2004). Further research is needed to investigate students' m-learning experiences outside the classroom, and their impact on learning. Only then will we be able to exploit the affordances of m-learning across diverse locations.

As well as clearly indicating students' perceptions of the value of particular m-learning pedagogies, the findings shed light on the differences between m-learning in mathematics and science. A comparison of students' experiences across these two disciplines indicates that authentic m-learning, though low in its occurrence, was more likely to be experienced in science subjects. There were no significant differences in the students' experiences across mathematics and science with respect to levels of personalisation or collaborative m-learning pedagogy. However, science students did report a significantly higher level of perceived improvement in their learning because of using mobile technologies, relative to mathematics students' m-learning experiences. This is consistent with the survey of teachers (Kearney, Burden, Schuck, Burke, & Aubusson, 2020), which reported similar differences. Our findings indicate that science appears to have made ground upon mathematics with respect to improving learning experiences, with the latter previously having benefited from a legacy of use that enabled teachers in this subject area to more smoothly adapt to m-learning (Sutherland, 2004).

Although we conducted this research in schools adopting extensive use of mobile devices for teaching and learning, we were acutely aware that mobile devices were being used in a school system and with a curriculum that evolved in a past environment when mobile devices were rare and limited to personal and professional communication. Consequently, it is unsurprising that more flexible and pedagogically diverse ways of learning with these tools do not occur frequently. Schooling has not been structured to encourage learning outside of the classroom or home, nor at times of students' choosing; and it is not designed to promote seamless learning across boundaries of formal and informal learning spaces (Schuck & Maher, 2018). The signature m-learning pedagogies of personalisation, authenticity, and collaboration described in the iPAC Framework may be forerunners of curriculum and schooling to come. Student voice, as evidenced in this study indicates that signature m-learning pedagogies are perceived as attractive to students and as contributing to their learning.

A significant outcome of this study is the provision of a validated and reliable student survey instrument that can be used to uncover secondary school students' typical m-learning experiences. This robust instrument could be utilised in future studies exploring students' changing experiences over time, for example, as part of an investigation into a school or class-based teaching intervention or initiative. Another use would be to investigate m-learning experiences in other contexts, or to explore the experiences of learners in other age groups, such as in elementary/primary school education, as well as across other disciplines in the humanities and the creative arts. The survey could also be used to investigate the provision of inclusive m-learning experiences, and to probe the context of remote learning beyond school. This article is written at the time of a global pandemic. It may be that the increase in remote learning experienced at this point is a turning point for new practices using mobile devices in learning. If so, listening to student voices regarding distinctive signature m-learning pedagogies may provide guidance to teachers on how to enhance learning at this challenging time.

Limitations

This article reports on one part of a large mixed-methods study. Here, we have focussed on the findings of a single method, a survey of students' perceptions. The article discusses the investigation of students' perceptions of learning with mobile devices. It would be useful to triangulate the study with actual learning outcomes. In addition, this study was conducted in four schools where access to and use of mobile devices are above that of typical levels currently observed in many secondary schools. This has implications for the generalisability of the findings. In addition, our research focuses on learning outcomes with respect to mathematics and science only. It would be worthwhile to further validate the instrument in other subject settings to assess pedagogical aspects of iPAC as precursors to improved perceived learning outcomes that have been reported, such as in the contexts of history (Huizenga et al. 2009), English (Çetinkaya & Sütçü, 2018), and geography (Scanlon et al. 2011).

Conclusions

The study developed a student survey with strong reliability and validity of the chosen measures. The empirical findings from the survey offer critical insights into how students viewed different pedagogical experiences of m-learning and perceived improvement in learning across mathematics and science. Numerous research studies report on teachers' perceptions of the value of m-learning. Whilst it is acknowledged that teachers hold a valuable and unique perspectives on the role of technology (Khlaif, Gok, & Kouraïchi, 2019) – and thereby are important stakeholders in a participatory design process (Cober, Tan, Slotta, So, & Könings, 2015) – our study equally acknowledges the valuable and unique perspective of the student voice in informing m-learning pedagogy. Few studies approach the students directly to gain their views about their typical m-learning experiences or the extent to which their use of mobile devices may or may not improve learning. Hence, the value of the approach taken in this study is that the findings are derived from student perceptions of their typical, everyday m-learning experiences rather than of their experiences linked to an imposed intervention. These findings have implications for the ways in which teachers use mobile devices for teaching, particularly in secondary mathematics and science. One clear implication is that student learning might benefit from higher levels of personalisation, authenticity, and collaboration in their m-learning activities.

Acknowledgements

The authors wish to acknowledge the financial support provided by the Australian Research Council Discovery Project 'Optimising Teaching and Learning with Mobile Intensive Pedagogies' (ARC-DP 150101214).

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Table 1
Descriptive Statistics

	Maths (n=572)	Science (n=307)	Combined (n=879)
School location (Australian state)	%	%	%
New South Wales	81.6	77.2	80.1
Victoria	18.4	22.8	19.9
Type of school (funding system)			
Government	94.8	95.4	95.0
Non-government	5.2	4.6	5.0
Type of student (gender)			
Co-educational	81.1	35.8	65.3
Girls only	18.9	64.2	34.7
Level of enrolment			
Year 7 (aged 12 - 13 years old)	30.8	21.8	27.6
Year 8 (aged 13 - 14 years old)	20.5	22.5	21.2
Year 9 (aged 14 - 15 years old)	29.5	34.9	31.4
Year 10 (aged 15 - 16 years old)	19.2	20.8	19.8
Mobile technologies used most often to help you learn in school			
Tablet	34.3	63.5	44.5
Laptop	18.9	12.1	16.5
Smart phone	26.2	5.2	18.9
iPod Touch	1.0	2.3	1.5
Netbook	0.0	0.0	0.0
Other	9.3	16.6	11.8
None	10.3	0.3	6.8
Ownership of m-learning device			
Own device	92.1	87.9	90.7
School - for use in and beyond school	4.5	10.7	6.7
School - for use at school only	1.0	0.7	0.9
Other	2.3	0.7	1.7
Use of mobile devices in 'everyday' life (i.e. not for schoolwork)			
(1) Never	1.9	2.0	1.9
(2)	4.0	2.0	3.3
(3)	8.9	13.0	10.4
(4)	14.5	19.5	16.3
(5) Often	70.6	63.5	68.1
Mean (standard deviation) usage - out of 5	4.48 (.95)	4.41 (.93)	4.45 (.94)
Confidence in using mobile device			
(1) Not at all confident	0.7	0.3	0.6
(2)	1.6	1.3	1.5
(3)	10.8	9.4	10.4
(4)	31.6	34.2	32.5
(5) Very confident	55.2	54.7	55.1
Mean (standard deviation) confidence - out of 5	4.39 (.80)	4.42 (.74)	4.40 (.78)

Table 2

Factor Loadings and Mean Differences (PAC components)

		Aggregate (n=878)		Maths (n=572)		Science (n=306)		Comparison between Maths and Science			
Latent Factors and Measurement Items	**Loadings**	**M**	**SD**	**M_M**	**SD**	**M_S**	**SD**	**(M_M-M_S)**	**SE**	**t-stat**	**p-val.**
Personalisation (P) *AVE= .653; CR=.849; CA=.807*	-	3.35[a]	1.24	3.31[a]	1.26	3.42[a]	1.21	-0.106	0.087	-1.221	0.222
P1. I choose the place(s) to work, e.g., bus, home, playground	0.841	3.19[a]	1.30	3.14[a]	1.29	3.27[a]	1.30	-0.135	0.092	-1.466	0.143
P2. I decide the time to work, e.g. after school, on weekend, during class	0.839	3.56[a]	1.20	3.54[a]	1.20	3.59[a]	1.18	-0.050	0.084	-0.591	0.555
P3. I work the way I want to, e.g. write, draw, narrate, animate, video	0.739	3.30[a]	1.23	3.26[a]	1.28	3.39[a]	1.14	-0.134	0.084	-1.582	0.114
Authenticity (A) *AVE= .578; CR=.872; CA=.759*	-	2.29[d]	1.16	2.19[d]	1.17	2.48[d]	1.17	-0.286	0.082	-3.477	0.001***
A1. Learn in a place suggested by the topic, e.g., learning about stars under the night sky; learning about pollution at a local stream, find height of a flagpole in the school	0.747	2.42[d]	1.22	2.28[d]	1.18	2.67[d]	1.26	-0.388	0.087	-4.445	0.000***
A2. Learn in a realistic virtual space/site, e.g., use of augmented (AR) or virtual reality (VR) apps, science simulation	0.788	2.10[d]	1.14	1.97[d]	1.13	2.33[d]	1.13	-0.360	0.080	-4.492	0.000***
A3. Learn through a community activity/project, e.g., Platypus census using platypusSPOT app; environment projects such as bush regeneration or water quality	0.819	2.03[d]	1.08	1.93[d]	1.06	2.22[d]	1.09	-0.289	0.077	-3.769	0.000***
A4. Work more like an expert e.g. collect data using GPS, compass, map, camera; measure using an inclinometer app	0.735	2.43[d]	1.17	2.39[d]	1.18	2.52[d]	1.15	-0.131	0.082	-1.605	0.109
A5. Consider experts' views on the topic, e.g., from a science TED-Ed Talk, or mathematician's YouTube channel	0.704	2.49[d]	1.25	2.39[d]	1.24	2.66[d]	1.24	-0.264	0.088	-2.994	0.003***
Collaboration (C) *AVE=.576; CR=.803; CA=.759*	-	2.28[d]	1.27	2.29[d]	1.30	2.26[d]	1.21	0.036	0.088	0.405	0.686
C1. Make something together with friends, e.g., make a video, photo, document, wiki; build something in Minecraft	0.736	2.58[d]	1.27	2.52[d]	1.30	2.69[d]	1.22	-0.174	0.088	-1.970	0.049**
C2. Exchange something with others online, e.g., playing a multi-player game, tagging a video, commenting on a photo	0.792	2.25[d]	1.37	2.32[d]	1.40	2.12[d]	1.31	0.203	0.095	2.133	0.033**
C3. Share and compare items generated on my device with others, e.g., Fitbit data such as 'steps walked', pocket money budget; sharing a photo	0.747	2.02[d]	1.17	2.05[d]	1.20	1.97[d]	1.11	0.078	0.081	0.966	0.334

Note: [a] and [d] mean response indicates students were significantly more likely to agree/disagree with this statement (M=3) at .05 level.

Note: */**/*** differences in means (maths vs science) significant at .05/.01/.001 level. AVE=Average Variance Extracted; CR=Composite Reliability; CA=Cronbach's Alpha.

Table 3:

Factor Loadings and Mean Differences (Endogenous and Exogenous components)

		Aggregate (n=878)		Maths (n=572)		Science (n=306)		Comparison between Maths and Science			
Latent Factors and Measurement Items	**Loadings**	**M**	**SD**	**M_M**	**SD**	**M_S**	**SD**	**(M_M-M_S)**	**SE**	**t-stat**	**p-val.**
Outside classroom location (O) *AVE= .692; CR=.871; CA=.832*	-	2.38[d]	1.30	2.44[d]	1.34	2.26[d]	1.21	0.171	0.089	1.914	0.056*
O1. Out of the classroom but at school, e.g., hall, playground	0.838	2.53[d]	1.25	2.55[d]	1.27	2.48[d]	1.22	0.067	0.087	0.768	0.443
O2. Excursions, e.g., excursion site, museum	0.815	2.17[d]	1.22	2.26[d]	1.28	2.01[d]	1.09	0.250	0.082	3.051	0.002***
O3. Other places, e.g., on bus, in coffee shop, shopping centre	0.843	2.43[d]	1.43	2.50[d]	1.47	2.30[d]	1.34	0.194	0.098	1.981	0.048**
Perceived improvement in learning (PIL) *AVE= .761; CR=.905; CA=.872*	-	4.90[a]	1.62	4.77[a]	1.72	5.13[a]	1.38	-0.364	0.107	-3.407	0.001***
PIL1. Using mobile devices has improved my learning in school {Maths/Science}	0.820	5.00[a]	1.62	4.85[a]	1.71	5.27[a]	1.38	-0.421	0.107	-3.954	0.000***
PIL2. Using mobile devices helps me to understand concepts in school {Maths/Science}	0.900	4.86[a]	1.59	4.74[a]	1.70	5.10[a]	1.35	-0.364	0.105	-3.464	0.001***
PIL3. Using mobile devices helps me to practise school {Maths/Science} skills	0.896	4.83[a]	1.65	4.72[a]	1.76	5.03[a]	1.41	-0.308	0.109	-2.818	0.005***

Note: [a] and [d] indicate students, on average, were significantly more likely to agree/disagree with statement (M=3 for outside classroom location; M=4 for perceived improvement in learning).
Note: */**/*** differences in means (maths vs science) significant at .05/.01/.001 level.
M=mean; SD=standard deviation; SE=standard error; AVE=Average Variance Extracted; CR=Composite Reliability; CA=Cronbach's Alpha.

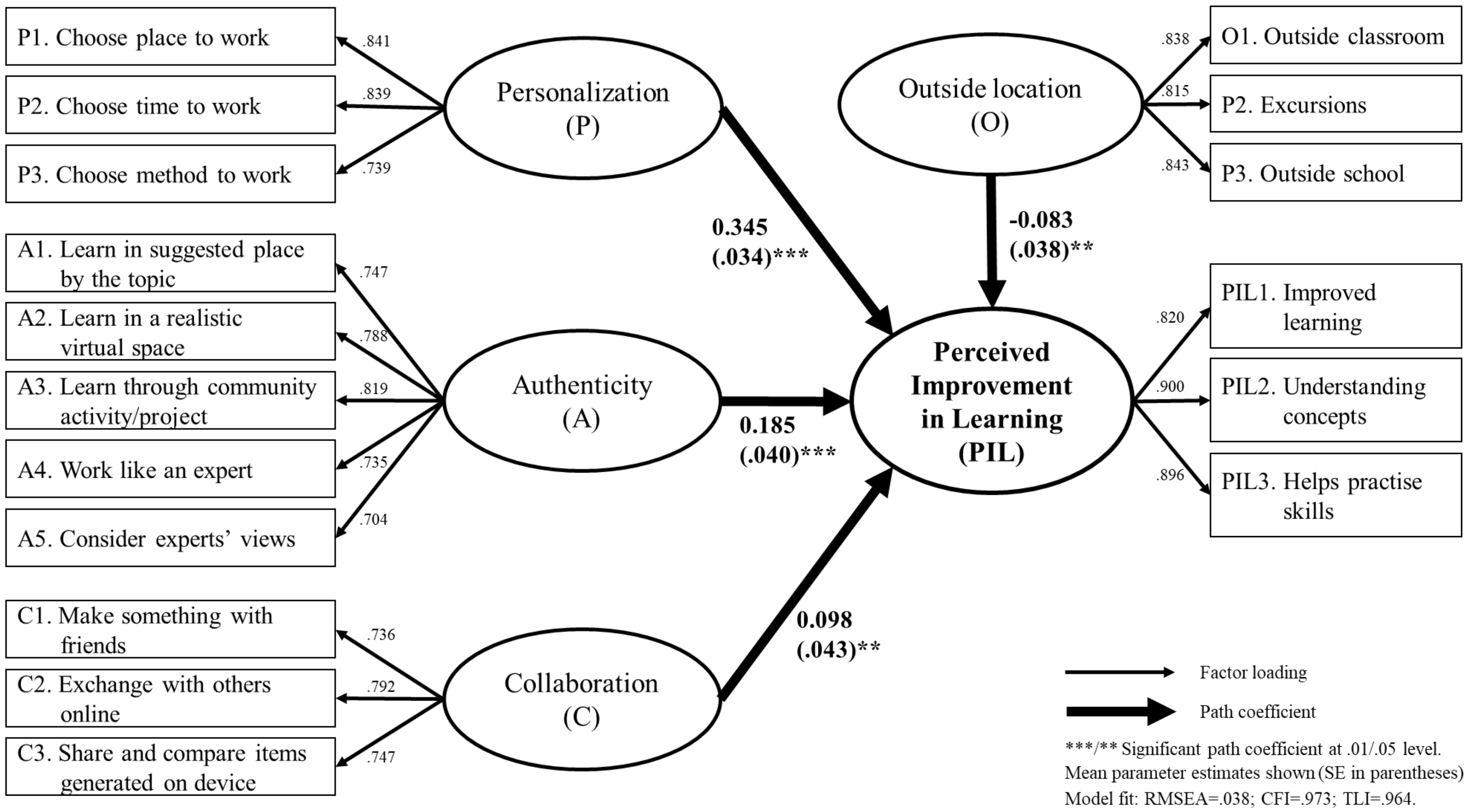

Figure 1. **SEM Results**