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Mediating learning with mobile devices through pedagogical innovation: Teachers' perceptions of K-12 students' learning experiences☆

Paul F. Burke[a,*], Sandy Schuck[b], Kevin Burden[c], Matthew Kearney[b]

[a] UTS Business, University of Technology Sydney, PO Box 123, Broadway, NSW, 2007, Australia
[b] Faculty of Arts and Social Sciences (FASS), University of Technology Sydney (UTS), University of Technology Sydney, P.O. Box 123, Broadway, NSW, 2007, Australia
[c] Faculty of Arts Cultures and Education, University of Hull, Postal: Cottingham Road, Hull, HU6 7RX, United Kingdom

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ABSTRACT

This article presents a quantitative study demonstrating that digital pedagogy using mobile devices (e.g., laptops, mobile phones, tablets) impacts teachers' perceptions of pedagogical innovation. We further find that innovative mobile pedagogy adoption positively impacts teachers' perceptions of improved student learning in K-12 settings. Examining teachers' perceptions of pedagogical innovation in digital practice is important as researchers have questioned whether the use of digital devices constitutes an innovative break with traditional pedagogical practice or serves merely as a digital replica of non-digital practices. Further, providing a link between pedagogical innovation and perceived improvements in student learning provides further support for removing barriers to innovation adoption. The study uses the validated iPAC Framework (referring to Personalisation, Authenticity and Collaboration in mobile teaching pedagogies) as the basis of an international survey. The survey measured teachers' perceptions of their adopted pedagogies using mobile technologies during students' completion of a digital task, whether they viewed these practices as innovative, and how such approaches impacted teachers' perceptions of their students' learning experiences. Results from a Structural Equation Model (SEM) demonstrate that when teachers adopt innovative pedagogical tasks into their teaching with digital technologies, they perceive an improvement in student learning experiences. This is the first study that considers both the contribution of digital pedagogies and the contribution of innovation as direct and indirect effects on teachers' perceptions of student learning experiences.

1. Introduction

As mobile technologies have become increasingly ubiquitous in society, their use in education for learning purposes has become more prevalent and common, a phenomenon referred to as 'mobile learning' (Al Saleh & Bhat, 2015; Kearney, Burke, & Schuck, 2019; Crompton & Burke, 2020; Crompton et al., 2017). Mobile learning (or 'm-learning') refers to the use of a growing range of digital

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* Corresponding author.
E-mail addresses: paul.burke@uts.edu.au (P.F. Burke), sandy.schuck@uts.edu.au (S. Schuck), K.J.Burden@hull.ac.uk (K. Burden), matthew.kearney@uts.edu.au (M. Kearney).

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technologies in education – including laptops, mobile phones, and tablet devices – all characterised by their portability, accessibility, and connectivity (Traxler, 2021). Definitions of 'm-learning' emphasise how the inherently untethered nature of mobile technologies (Schuck, 2016; Schuck, Kearney, & Burden, 2017; Traxler, 2018) facilitate learning across a variety of learning contexts (Crompton et al., 2017).

Research studies and reviews into the phenomenon of m-learning in schools have identified several positive benefits, including the ability to enrich student learning experiences (Burke & Aubusson, 2020; Crompton & Burke, 2020; Crompton et al., 2017; Lai et al., 2016; Qureshi et al., 2020; Sung et al., 2016; Wu et al., 2012). Many of these studies have focused on the perceptions and beliefs of teachers reporting the impact of their own and students' use of mobile and digital technologies on their students' learning (Schuck, 2016; Schuck et al., 2017; Chiu & Churchill, 2016; Tondeur et al., 2017). These studies demonstrate how teachers have explored alternative pedagogical practices enabled by the affordances of mobile technologies. This raises a contentious issue amongst researchers and practitioners alike questioning whether the use of digital devices, such as mobile phones and tablets, constitute an innovative break with traditional pedagogical practices or whether the use of digital devices are merely a substitute for non-digital practices (Sailer et al., 2021; Selwyn, 2021; Traxler, 2021). This is a complex issue and much of the debate is dependent on the definitions of innovation.

In defining the term 'innovation', we draw upon a diverse range of theorists and practitioners from a variety of discipline areas who have sought to clarify this term (e.g., Burden, Kearney, Schuck, & Hall, 2019; Christensen et al., 2008; Cranmer & Lewin, 2017). Based on the outcome of an extensive large-scale Systematic Literature Review (SLR) focused on innovative mobile pedagogies undertaken by Burden, Kearney, Schuck, and Hall (2019) , we acknowledge the wide variety of definitions used by educators and researchers to capture the essential elements of this term. Whilst most commentators across discipline areas accept the premise that innovation must bring about change (Castaneda & Cuellar, 2020; Fagerberg, 2009; Hund et al., 2021), there is less certainty about what kind of changes constitute innovation, with its conceptualisation often pointing towards its consideration on a continuum. At one extreme, sustaining or incremental innovation is defined as change that modifies existing pedagogical practices but does not transform their underlying principles or approaches (Christensen et al., 2008; Cranmer & Lewin, 2017). Disruptive or radical innovation, at the other end of the continuum, identifies changes that create new practices, challenging existing paradigms of pedagogy. Our adopted definition of innovative mobile pedagogies (i.e., what we refer to as 'm-innovation') is that it refers to new approaches, designed to take advantage of mobile devices to support effective learning, as perceived by stakeholders, in ways and contexts that could not otherwise occur without mobile devices (). These practices are different from conventional approaches and suggest new ideas or practices that are impactful and valuable to individuals or communities" (Kearney, Burden, & Schuck, 2019a).

Whilst several previous studies have explored the relationship between teachers' beliefs and attitudes and their use of digital technologies in the classroom (Tondeur et al., 2017), these studies do not explore the impact or effect that innovation brings about in this process. Hence the importance of the current study is that it aims to explore the extent to which the use of carefully chosen mobile pedagogies create innovative practices and to what extent these approaches positively impact teacher's perceptions of improvements in student learning experiences.

The digital pedagogies under scrutiny here are described by the iPAC Framework, a socio-cultural framework consisting of three major pedagogical dimensions characteristic of m-learning: personalisation, authenticity, and collaboration ((Kearney, Schuck, Burden, & Aubusson, 2012). Further, each dimension is divided into sub-dimensions, which have been empirically modified over the last decade ((Kearney, Burke, & Schuck, 2019). We offer a further contribution to the literature by developing a new reflective measure of innovative mobile practices, m-innovation, empirically validating its reliability and construct validity. Using structural equation modelling incorporating existing and developed measures of the focal learning constructs – i.e., the iPAC pedagogies, m-innovation, and perceived improvement in student learning experiences (or PISLE) – the research offers an empirical study of whether the impact of iPAC digital pedagogies on PISLE is mediated by m-innovation. That is, the research approach considers two aspects simultaneously: namely, to investigate if: a) adoption of iPAC mobile pedagogies are perceived as innovative teaching by teachers; and b) innovative mobile practices lead to teachers' perceptions of improved student learning experiences. This is the first study that considers both the contribution of the iPAC m-pedagogies and the contribution of innovation as direct and indirect effects on teachers' perceptions of improved student learning experiences. To summarise, the overarching research question for this study asks:

> "*Are teachers' perceptions of improved student learning experiences impacted by their iPAC pedagogical practices* via *the mediating role of digital pedagogical innovation?*"

In the following sections, the iPAC digital pedagogical framework is summarised along with a short history of its genesis. The concept of digital pedagogical innovation is analysed and related to past and present studies. Following this, the quantitative study is introduced.

2. Background literature

2.1. The iPAC framework and K-12 students' learning

The iPAC Framework, originally known as the Mobile Pedagogical Framework, was developed by Kearney et al. (2012), to provide a model for mobile learning. Underpinned by socio-cultural theory, the framework has become a lens to view the use of mobile digital pedagogies and their potential for transforming learning (Burke & Aubusson, 2020). It comprises three dimensions, Personalisation, Authenticity, and Collaboration, as attributes of mobile learning, with each dimension subsuming two sub-dimensions (see Fig. 1). Time and space are included in the framework to account for different m-learning settings and environments.

Some studies have focused on just one of the iPAC dimensions. For example, Price et al. (2016), as well as Mettis et al. (2023), both examined how mobile technologies shaped students' exploration and experience of place. The experience of a physical site combined with a mobile digital experience supported new connections with and tangibility of historical events. Hwang and Chang (2016) found that a location-aware mobile learning approach combined with a competition significantly improved students' local cultural identity, interest, and attitudes to learning, while decreasing cognitive load when learning during a field trip. Sweeney et al. (2018) investigated how 3D visualisations of historical sites could be used as pedagogical tools. Learners could explore alternative viewpoints by interacting with historical virtual environments and utilise augmented reality that preserved and accurately restored the historical landscape over various places and times. McMullen et al. (2019) found that a project that exploited the ubiquitous nature of mobile technologies provided opportunities to extend connections with the real world and bring out-of-school contexts and problems into the mathematics classroom. More recently, Pugh et al. (2023) described findings from a study in which student participants took photographs when making connections with curriculum in their everyday lives, posting and captioning their images to a collaborative platform. The study warned of techno-determinist conclusions, emphasising that teachers' roles were critical in supporting any benefits to students' learning with mobile devices (rather than any technical features), such as bridging gaps between school and everyday experiences. Other studies have focused on the adoption of more than one of the iPAC dimensions.

Examples of studies that mainly focus on authenticity and collaboration follow. In another study using photography as the context, Herrick et al. (2022) encouraged students to bring their photographs of outside experiences back into the classroom to enhance the relevance of their learning and allow them to recast their experience in concert with their peers, the teacher, and the curriculum. Álvarez-Herrero (2023) described a mobile learning study set outside the classroom with secondary students. The students worked in groups to complete a route through a city, identify trees via an augmented reality application and to measure noise pollution with a mobile application. Their projects utilised smartphones with augmented reality, geolocation, and social networks and resulted in students' improved awareness and concern for environmental problems. Väljataga and Mettis (2022) investigated a student-centred outdoor mobile technology-enhanced collaborative inquiry learning project. They showed that the place-responsive pedagogy enhanced students' understanding of their environment. Lee (2020) conducted a project for high-school students to undertake inquiry-based learning in the field by posing questions, designing investigations, collecting and analysing data, drawing conclusions, and sharing findings. The results of the project demonstrated how inquiry-based activities undertaken via mobile technology facilitate teachers' perceptions of improved student learning processes, as well as increasing inquiry and collaboration skills.

2.2. Digital pedagogical innovation and K-12 students' learning

In previous work, Burden, Kearney, Schuck & Hall (2019) and Kearney, Burke & Schuck (2019) examined the nature of digital pedagogical innovation. We developed a set of principles for innovative digital tasks based on previous work by Law et al. (2005). Several criteria were identified as indicating innovative practice. These criteria considered the role of the teacher, learner (agency), relationships between students and teachers, as well as purpose and learning context. Using these criteria, Burke & Aubusson (2020) evaluated the existence of innovation in teaching practices. However, few studies have investigated links between innovative digital approaches and improved student learning experiences. This study adopts the iPAC Framework as a theoretical lens to consider these links.

Often the use of digital tools is seen as innovative in itself. A study of one-to-one computing practices showed that students' use of tablets in classrooms contributed to the destabilisation and redefinition of traditional teacher practice (Bergström &

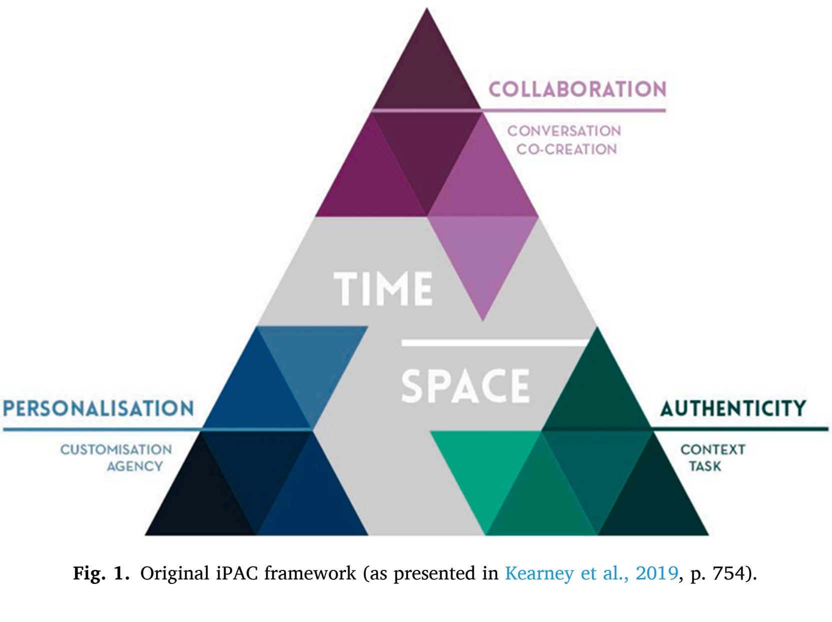

Fig. 1. Original iPAC framework (as presented in Kearney et al., 2019, p. 754).

Wiklund-Engblom, 2022). However, the teachers' beliefs were key to the way they implemented new digital tools in their classrooms. In a study of schoolteachers in New Zealand, Lindsay (2016) found that although the use of mobile technologies offered the potential for transformative pedagogical approaches through collaborative inquiry, informal learning, and situated learning using authentic contexts and expert contacts, the teachers' main pedagogical uses of mobile technology were for information access and innovative media production. The teachers in this study reported lower adoption of collaborative pedagogical approaches and that they seldom took the opportunities mobile technology offered for situated learning in context and connecting with experts.

Burden, Kearney, Schuck, and Hall (2019) conducted a systematic literature review exploring innovations in mobile digital pedagogies in schools. Analysis of the fifty-seven papers that met the criteria for discussing the innovative use of mobile pedagogies showed low to medium degrees of innovation, with only three papers (Akom et al., 2016; Barak & Ziv, 2013; Toh et al., 2017) showing highly innovative, disruptive mobile learning practices. Such practices were characterised as creating new educational purposes or processes and fundamentally altering existing approaches and practices, such as the student-teacher relationship, and enabling learning to occur in ways and contexts unable to occur without mobile devices (Burden, Kearney, Schuck, & Hall, 2019) For instance, the researchers considered practices in the Barak and Ziv (2013) study that incorporated pedagogical elements able to disrupt traditional approaches. In this study, students used a web-based platform to facilitate outdoor and interactive learning. Using the program, students designed and created location-based interactive learning objects, sharing these with their community via social media. Since such learning objects are traditionally created by teachers, this represents a potential disruption of the status quo, along with the teachers taking on guiding roles and releasing control to encourage students' independent learning. Akom et al. (2016) incorporated a digital platform in one activity, which allowed students to co-develop and participate in a health promotion within their community. The project focused on food availability, whereby participants mapped locations and information about retail stores in their urban area, making recommendations about healthy foods be stocked in stores. The activity was disruptive as it was a different way of working with students, promoting activism and authority; taking place in an authentic environment and the participants co-designed the app using real-world processes to map and analyse their locality. In the third paper, Toh et al. (2017) described two case studies where children used mobile devices to link their personal interests and situations to support their science learning across informal and formal learning contexts. All three studies included high levels of student autonomy, including how, where, and when students completed their task and demonstrated learning. The relationship between students and teachers was also more democratic than normal; learning occurred across multiple contexts; and the use of the mobile device linked contexts, ensuring more authentic and meaningful learning (Burke & Aubusson, 2020).

A study by Väljataga and Mettis (2022) investigated whether mobile outdoor learning could support students' learning relating to environmental topics and to connect in-school knowledge with out-of-school experience. Results showed the project impacted students' factual knowledge growth and fostered conceptual change. The project also investigated the students' need for conceptual and procedural scaffolding. The study utilised an innovative learning design that included student-centred open inquiry-based learning, outdoor authentic learning across different contexts, and a real-life environmental challenge. The learning design followed place-responsive pedagogy with a focus on place-essential teaching strategies and used mobile technologies as a scaffolding and guiding tool during the collaborative inquiry process (Fu & Hwang, 2018). A mobile application "replaced" the teacher and instructed the students through the inquiry phases. Students seldom reported problems and challenges but obtained greater scientific understanding with a more holistic view that connected learning tasks with relevant real-world socio-environmental problems.

Wang et al. (2023) found that secondary students improved creative-thinking skills following a Geography learning activity where they generated ideas in mobile augmented reality (AR) applications, created media resources and digital learning video games, and interacted with their peers and teachers in a remote online format. The students demonstrated a higher level of progress in the development of creative thinking skills than students in a control group, who learned in a traditional classroom. This project incorporated innovative pedagogical principles such as student agency, real-world tools, artefact construction, seamless learning, reflection, co-construction, customisation, simulation, student autonomy, peer review, data sharing, digital play, and gamification (Burden, Kearney, Schuck, & Hall, 2019).

While the studies above explore the use of innovative digital practices, evidence linking such practices with enhanced student learning experiences is scarce.This article uses a quantitative methodology to demonstrate the mediating effects of innovation on teachers' perceptions of improved student learning experiences.

3. Study design

3.1. Conceptual model

Mediation exists when a predictor - in this case, the iPAC sub-dimensions - affects a dependent variable (teachers' perceptions of improved student learning experiences, or PISLE) indirectly through an intervening variable (digital pedagogical innovation, or m-innovation). Mediation analysis provides "a story about a sequence of effects that leads to something" (Kenny, 2008, p. 2). In this study, we use such analysis to understand the mediating process by which teachers' adoption of the iPAC dimensions (digital pedagogies) can affect students' learning experiences both directly and indirectly through their impact on teachers' levels of digital pedagogical innovation. To facilitate the comparison, we present a representation of the proposed conceptual model focusing on how iPAC pedagogies impact learning experiences and the mediating role of m-innovation (i.e., pedagogical innovations involving mobile digital devices). This relationship is depicted in Fig. 2, adapting the standard mediation model for the current context (Baron & Kenny, 1986; Hayes, 2009; Zhao et al., 2010). The relevant equations for this representation and the tests required follow the proposed mathematical representation of mediation first offered by Judd and Kenny (1981).

3.2. Instrument development

Our empirical study utilised an online survey of teachers to elicit their views of their school students' experiences, asking them to reflect on a recently implemented digital activity of their own choosing. The teacher survey participants nominated the discipline area and level (e.g., Year 8 math) of their chosen activity. With this activity context in mind, they then completed the survey concerning the six sub-dimensions of the iPAC Framework and overall PISLE.

The survey also included a measure of the proposed mediator, m-innovation, capturing teachers' views of whether their activity had fundamentally changed their students' learning experiences relative to their typical approach without mobile devices. Finally, teachers were asked to report on their teaching experience (e.g., number of years teaching) and provide details about their particular teaching context (e.g., ownership of mobile devices).

The current study utilised empirically validated measures of the two sub-dimensions of each of the three iPAC components, as used by Kearney, Burke, & Schuck (2019), but excluded items that they had reported as unreliable measures (e.g., "Engaged in learning content that was relevant to them" did not share a common variance with other measures of context). The dependent variable, teachers' perceptions of improved student learning experiences, also utilised the five-item measure validated by Kearney, Burke, & Schuck (2019).

The mediating variable, m-innovation, was a newly proposed measure focused on capturing fundamentally different approaches that teachers undertook when implementing their digital learning activity, relative to their approaches typically used without mobile devices. The measure was informed by the following four criteria, based on Law et al. (2005).

A. The purpose of learning (e.g. the curriculum; learning objectives, etc) and/or the nature of the task/activity and/or the embeddedness of mobile learning;
B. The context of the learning (e.g. the place or time in which learning is undertaken; pedagogical practices; mode);
C. The role of the teacher/educators and their relationship with the students (didactic; involving communities other than school);
D. The role of the learner (agency, passive).

We used these criteria to design a set of m-innovation survey items for teachers to assess the extent to which their digital task (in their nominated activity context e.g. Year 9 science) was different from typical tasks used in this context without digital devices. Items 1–4 (see below) aligned with the previously mentioned criteria A-D respectively, while the final item invited an overall assessment. Teacher participants in the survey were asked to consider their nominated digital activity and assess the previously mentioned differences in approaches by considering the extent to which.

1. Use of a digital device fundamentally changed the way that learning occurred
2. The context of learning was radically different in terms of setting, time, or mode of task
3. The range of stakeholders facilitating learning was greatly expanded (e.g. teachers, family, community members, and other experts)
4. Learners were granted significantly more agency than would normally be the case

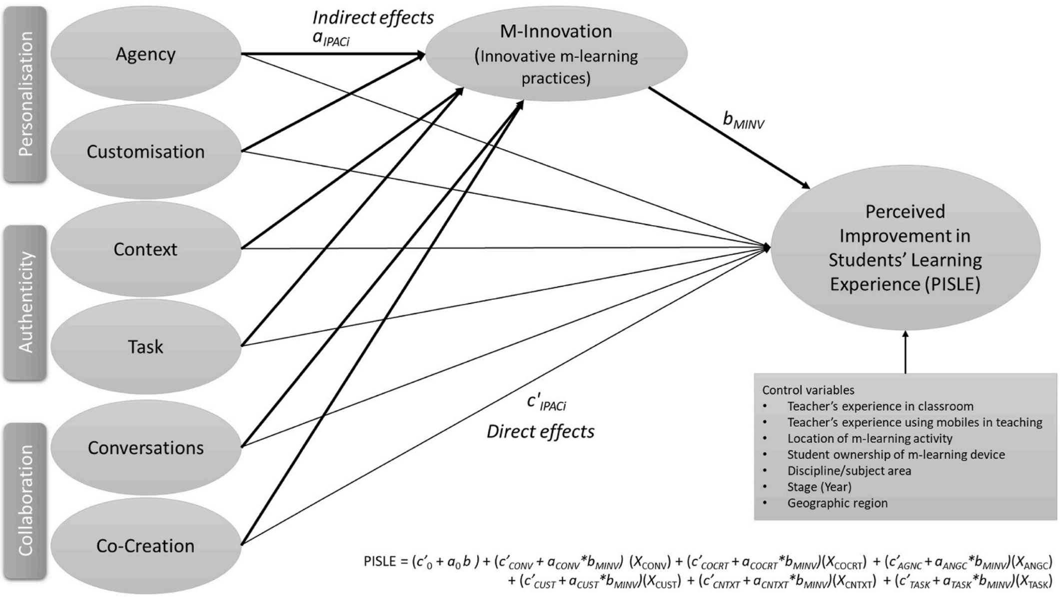

Fig. 2. Proposed conceptual model.

5. Learners' overall experience was fundamentally different from what they would normally experience in [activity context].

The final survey comprised twenty measurement items measuring the six sub-dimensions of the iPAC Framework, five items measuring m-innovation, and five items measuring PISLE. Each of these measurement items was evaluated by respondents on a five-point scale ranging from 1 to 5, where "1″ means "Strongly disagree" (SD) and "5″ means "Strongly agree" (SA).

Teachers were invited to participate in the online survey using three approaches. Firstly, the survey was disseminated to teachers internationally via social media. Secondly, teachers who enrolled for a variety of workshops to be provided by the authors were asked to complete the survey as part of their enrolment *before* attending these sessions. The workshops were conducted at digital education conferences in Europe, the UK, Australia, and the US. Finally, pre-service teachers from universities were also invited to complete the survey while they were on their professional internships in schools.

In turn, several additional survey measures were included to gauge teacher experiences and differences in their backgrounds, including the country in which they taught, their experience in classroom teaching, and ownership arrangements relating to the mobile devices that students used (e.g., BYOD). These were included as control measures in the empirical testing of the proposed conceptual framework. Before commencing the survey, teachers were provided an overview of the survey, assurance of their anonymity if agreeing to participate, and an opportunity to decline participation at any time as part of the ethics approval agreement (UTS Human Research Ethics Committee, ETH20-5007).

3.3. Participants

In total, complete survey responses were received from 480 K to 12 schoolteachers. Table 1 presents a description of participating teachers across a range of measures. The sample included 53.5% in-service teachers with a median of 10–20 years of classroom teaching experience among them, the balance being pre-service teachers. A total of 43 countries were represented in the survey, with Spain having the largest representation of in-service teachers (19.1%), followed by Australia (10.5%), Norway (9.3%) and the United Kingdom (6.6%). The majority of pre-service teacher participants were from Australia (79% of pre-service teachers) and Germany (9.4%). There was a broad variety of experience in mobile pedagogies amongst teachers, with the largest cohorts being occasional users (34%) and experienced users (33%).

Table 1 also describes the chosen m-learning activity that teachers nominated and evaluated against the measures of iPAC, m-innovation and overall teachers' perceptions of improved student learning experiences (PISLE). The modal response represented m-learning activities taking place in the classroom (36.7% of nominated activities), undertaken by students who used mobile devices owned by their school for use at the institution only (42.4%). The majority of teachers nominated m-learning activities that took place in a primary school setting (54.8%), much of these occurring with infant students. The chosen activity reported upon represented more than 21 subject areas, with teachers more likely to report on activities in English (36.5% of activities), Science (13.8%), Mathematics (8.5%), or Languages other than English (8.5%). Another 18 subjects were represented by less than 4% of the sample (i.e., no more than 19 teachers) in each case.

3.4. Reliability and validity of measures

The reliability of the focal dependent variable, the reported perceived improvement in students' learning experiences (PISLE) following their participation in the nominated digital activity, was assessed using reliability and confirmatory factor analysis (CFA). Concerning reliability, Cronbach's Alpha was $\alpha = .88$, whilst the Composite Reliability (CR) was 0.943, above the required benchmark of 0.75 (Fornell & Larcker, 1981; Nunnaly, 1978; Raykov, 1997). All factor loadings were greater than the benchmark of 0.71 (Hair et al., 2009) except one reverse-coded item ("My <year level> students found it difficult learning < discipline area > using mobile devices"). The remaining four items resulted in a measure of a single latent dimension, with the average variance extracted (AVE) being 0.806, above the required benchmark of 0.5 to establish convergent validity (Fornell & Larcker, 1981). Hence, the reliability and validity of the focal dependent variable using the remaining four items, PISLE, is established. Details of these are reported in Table 2.

There was a total of 20 items evaluated by teachers as being potentially representative of the six sub-dimensions of the iPAC Framework. Both exploratory factor analysis (EFA) and subsequent confirmatory factor analysis (CFA) showed the presence of the six iPAC dimensions as latent factors as anticipated. Specifically, all items loaded onto their respective focal construct without any concerns about cross-loading (Chin, 1998) and all factor loadings exceeded 0.71 as required (Hair et al., 2009).

Each of the six iPAC constructs had an AVE that was higher than the necessary threshold of 0.5 to establish convergent validity (Fornell & Larcker, 1981). Reliability was also established via Cronbach Alpha's (CA) and Composite Reliabilities (CR), with both measures greater than 0.7 for each latent construct (Fornell & Larcker, 1981; Nunnaly, 1978; Raykov, 1997). Following Fornell and Larcker (1981), discriminant validity was established by confirming that the squared correlation of any two items was less than their respective AVEs, with the final CFA's maximum cross-loading being 0.339 indicating that the results are unaffected by excessive levels of multicollinearity. The Variance Inflation Factors (VIF) of the structural models' inner components were below three and less than the advised threshold of five (Kline, 2018) and 3.3 (Kock & Lynn, 2012).

The newly proposed measure of m-innovation was also evaluated: all items had factor loadings above 0.71 (Hair et al., 2009), with AVE = 0.671, CA = 0.92 and CR = 0.91 indicating strong reliability and above accepted benchmarks (Fornell & Larcker, 1981; Nunnaly, 1978; Raykov, 1997). Hence, the reliability and validity of the mediating variable, m-innovation, using the five proposed measurement items is established.

Table 1
Descriptive statistics and Differences Across Latent Constructs.

Teacher or teaching context	n	%	Collaboration		Personalisation		Collaboration		Outcome/Mediator	
			Conversations	Co-Creation	Agency	Customisation	Context	Task	M-Learning	M-Innovation
			Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)
Years as a classroom teacher:										
Pre-service	223	46.5	2.54(1.07)∼	3.09(1.16)	2.91(1.04)	2.74(1.15)∼	2.77 (1.17)∼	2.91 (1.09)	3.54(0.86)ˆ	3.28(1.04)ˆ
Less than 2 years	25	5.2	2.44(0.97)∼	2.80(1.27)	2.75(1.14)	2.33(0.94)∼	2.55 (1.15)	2.87 (1.14)	3.40(0.77)ˆ	2.95(0.85)*b
2–9 years	82	17.1	2.50(1.22)∼	3.18(1.19)	3.06(1.09)	2.69(1.13)∼	2.74 (1.11)∼	2.96 (1.08)	3.81(0.84)ˆ	3.57(0.83)ˆ
10–20 years	85	17.7	2.78(1.09)	3.25(1.12)ˆ	2.90(1.13)	2.51(1.06)∼	2.4(1.13) ∼*b	2.75 (1.06)∼	3.87 (0.78)ˆ*a	3.39(0.95)ˆ
20+ years	65	13.5	2.41(0.98)∼	3.37(1.11)ˆ	2.97(1.08)	2.71(1.00)∼	2.73 (1.15)	2.90 (1.00)	3.73(0.77)ˆ	3.54(0.96)ˆ
Mobile devices in teaching:										
Inexperienced	114	23.8	2.35(1.04)∼	2.87 (1.19)*b	2.72(1.11) ∼	2.55(1.13)∼	2.63 (1.13)∼	2.69 (1.03)∼	3.38 (0.89)**b	3.22(1.05)
Occasional user	165	34.4	2.55(1.06)∼	3.13(1.13)	2.95(1.04)	2.64(1.05)∼	2.62 (1.12)∼	2.90 (1.07)	3.66(0.85)ˆ	3.22(0.97)ˆ
Experienced	159	33.1	2.61(1.12)∼	3.26(1.14)ˆ	2.98(1.06)	2.79(1.16)∼	2.73 (1.16)∼	2.97 (1.08)	3.79(0.76)ˆ	3.53(0.92)ˆ
Very experienced	42	8.8	2.92(1.09)*a	3.63 (1.07)**a	3.34 (1.06)*a	2.59(1.02)∼	2.90 (1.29)	3.05 (1.12)	3.98 (0.65)**a	3.79 (0.76)**a
Location(s) of m-learning:										
In the classroom	301	36.7	2.49(1.06)∼	3.16(1.19)ˆ	2.84(1.08) ∼	2.57(1.11)∼	2.59 (1.17)∼	2.82 (1.09)∼	3.68(0.86)ˆ	3.31(0.99)ˆ
On campus; Outside classroom	146	17.8	2.70(1.04)∼	3.48 (1.1)**a	3.22 (1.0)**a	2.78(1.08)∼	2.82 (1.22)	3.10 (1.09)*a	3.91 (0.75)**a	3.56(0.84)*a
Educational setting off campus	77	9.4	2.58(1.05)∼	3.39(1.03)ˆ	3.25 (0.94)**a	2.71(1.03)∼	2.92 (0.93)*a	3.07 (1.03)	3.83(0.78)ˆ	3.52(0.93)ˆ
At home	175	21.3	2.77(1.09) ∼*a	3.30(1.12)ˆ	3.2 (1.01)***a	2.82(1.14)∼	2.73 (1.14)∼	2.96 (1.03)	3.88 (0.78)**a	3.59(0.90)*a
Other location (e.g., café)	122	14.9	2.95(1.0)***a	3.51 (1.05)**a	3.40 (0.96)***a	2.84(1.06)	2.98 (1.15)*a	3.10 (1.09)	3.90 (0.77)**a	3.58(0.87)*a
Ownership of device:										
Institution - on campus only	191	42.4	2.46(1.08)∼	3.10(1.23)	2.84(1.08) ∼	2.58(1.14)∼	2.64 (1.22)∼	2.81 (1.09)∼	3.66(0.86)ˆ	3.30(1.04)ˆ
Institution – on/off campus	73	16.2	2.62(1.08)∼	3.49 (1.11)*a	3.12(1.01)	2.80(1.10)	2.85 (1.15)	3.03 (1.03)	3.80(0.83)ˆ	3.39(0.85)ˆ
Student owned	187	41.5	2.78(1.03) ∼*a	3.43 (1.0)**a	3.3 (1.0)***a	2.85(1.09)	2.81 (1.12)∼	3.02 (1.03)	3.9 (0.72)***a	3.63 (0.82)**a
Discipline area implementing:										
English	175	36.5	2.49(1.06)∼	2.99(1.20)	2.76(1.10) ∼	2.60(1.13)∼	2.52 (1.22)∼	2.65 (1.11) ∼*b	3.45 (0.91)*b	3.19(1.10)
Science	66	13.8	2.54(1.18)∼	3.43(1.16)ˆ	3.15(1.02)	2.75(1.16)	2.91 (1.10)	3.01 (1.02)	3.80(0.75)ˆ	3.50(0.85)ˆ
Mathematics	41	8.5	2.49(1.04)∼	3.11(1.04)	2.93(1.09)	2.58(1.05)∼	2.65 (1.18)	2.80 (1.00)	3.79(0.84)ˆ	3.35(0.89)ˆ
Language (other than English)	41	8.5	2.67(1.19)	3.07(1.24)	2.87(1.03)	2.51(1.11)∼	2.44 (1.10)∼	2.89 (0.95)	3.78(0.63)ˆ	3.39(0.97)ˆ
Other discipline area	157	32.7	2.61(1.06)∼	3.27(1.10)ˆ	3.05(1.07)	2.76(1.07)∼	2.84 (1.08)	3.10 (1.06)*a	3.77(0.81)ˆ	3.49(0.91)ˆ
Year level undertaking activity:										
Stage 1 (Kndgrtn; Yr 1 & 2)	140	29.2	2.2(1.1)∼***b	2.7(1.2) ∼***b	2.6(1.05) ∼**b	2.4(1.14)∼*b	2.41 (1.13) ∼*b	2.5(1.06) ∼**b	3.3 (0.96)***b	3.03 (1.13)**b
Stage 2 (Yrs 3 & 4)	70	14.6	2.64(0.97)∼	3.30(1.09)ˆ	3.05(1.13)	2.78(1.05)	2.75 (1.08)	3.10 (1.01)	3.63(0.75)ˆ	3.42(0.87)ˆ
Stage 3 (Yrs 5 & 6)	53	11.0	2.96(0.91)**a	3.6 (0.86)***a	3.16(0.78)	3.13(1.0)**a	3.21 (1.0)***a	3.23 (0.92)*a	3.83(0.65)ˆ	3.51(0.87)ˆ
Stage 4 (Yrs 7 & 8)	40	8.3	2.35(0.97)∼	3.14(1.28)	2.84(0.98)	2.76(1.10)	2.59 (1.23)∼	2.86 (1.20)	3.75(0.78)ˆ	3.37(0.99)ˆ

(continued on next page)

Table 1 (*continued*)

Teacher or teaching context	n	%	Collaboration		Personalisation		Collaboration		Outcome/Mediator	
			Conversations	Co-Creation	Agency	Customisation	Context	Task	M-Learning	M-Innovation
			Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)
Stage 5 (Yrs 9 & 10)	44	9.2	2.46(0.70)~	3.29(1.16)	2.73(1.11)	2.67(1.13)	2.40 (1.20)~	2.94 (1.15)	3.95 (0.86)^*a	3.47(1.00)^
Stage 6 (Yrs 11 & 12)	36	7.5	2.84(1.18)	3.40(0.94)^	3.09(0.96)	2.49(0.88)~	2.61 (1.25)	2.86 (1.06)	3.87(0.77)^	3.54(0.87)^
Country teacher resides										
Australia	203	42.3	2.54(1.07)~	3.18(1.14)^	2.97(1.06)	2.81(1.15)~	2.73 (1.18)~	2.87 (1.10)	3.60(0.85)^	3.32(1.06)^
Spain	50	10.4	2.17(0.88) ~**b	2.79(1.26)	2.71(1.06)	2.39(1.04)~	2.35 (1.12)~	2.71 (1.11)	3.69(0.96)^	3.21(1.15)
Germany	35	7.3	2.15(1.09) ~*b	2.90(1.21)	2.70(0.94)	2.21(1.00) ~*b	2.46 (1.23)~	3.07 (1.05)	3.68(0.76)^	3.23(0.88)
Norway	24	5.0	2.22(1.28)~	3.14(0.99)	2.99(0.72)	2.17(0.84) ~**b	2.83 (0.99)	2.66 (0.91)	3.70(0.60)^	3.34(0.70)^
United Kingdom	22	4.6	2.47(1.18)~	2.83(1.04)	2.82(1.26)	2.48(1.07)~	2.76 (1.25)	2.78 (1.15)	3.41(0.74)^	3.34(0.96)
Other country	146	30.4	2.86(1.04)**a	3.35(1.15)^	3.03(1.15)	2.79(1.07)~	2.75 (1.11)~	2.99 (1.02)	3.79(0.82)^	3.55(0.82)^* a
Aggregate	480	100	2.55(1.08)~	3.15(1.16)^	2.94(1.08)	2.66(1.10)~	2.68 (1.15)~	2.89 (1.07)~	3.67(0.83)^	3.37(0.97)^

*/**/*** differences significant at 0.05/0.01/0.001 level. ~/ indicates mean is significant above/below neutral mid-point (3) indicating agreement/disagreement.
a/b indicates mean is significant above/below aggregate mean.

4. Results

To answer the research question on the mediating effect of m-innovation in digital pedagogies on PISLE, we performed Structural Equation Modelling (SEM). These results are presented in Section 4.2. To ensure that all control variables were accounted for, we first examine teacher agreement on item responses and variation in teacher characteristics.

4.1. *Teacher agreement for each construct*

Teacher responses for each construct provided background information on the extent to which they agreed that their nominated teaching activity featured the eight constructs, relating to the six iPAC sub-dimensions, m-innovation, and PISLE (see Tables 1 and 2 for more details). The majority of teachers (58%) moderately agreed that their perceptions regarding PISLE had improved in their respective subject areas. The largest level of agreement occurred in relation to student enjoyment (66%) and levels of facilitation of students' practice of skills relating to the subject via the use of mobile devices (62%).

The means reported in Table 2, indicate the average extent that each reflective measure and their respective iPAC sub-dimensions featured in teachers' tasks. Overall, co-creation was most prominently featured (M = 3.15) followed by student agency (M = 2.94). At the other extreme, teachers indicated the level of collaboration in the form of student conversations was less prominent in their digital activities. Whilst the mean over all three measurement items for the conversation sub-dimension was 30.2%, very few teachers indicated that students had discussed the work online with people they did not know (12.1%).

Overall, 47.4% of teachers agreed that their m-learning activities were innovative. The largest level of agreement occurred in relation to teachers' indication that their perceptions of student learning had fundamentally changed in their respective subject areas (54% of teachers), with only 36.3% indicating that the range of stakeholders facilitating learning had not been greatly expanded (e.g. teachers, family, community members, and other experts) in their m-learning activity.

4.2. *Differences across teachers and teaching contexts*

Perceived levels of PISLE were significantly higher among teachers with greater experiences in using mobile devices, and higher among students undertaking activities out of their classrooms at their school or home, but not whilst on an organised off-campus activity (e.g., excursion). Teachers with students who used their devices at home also reported a significantly higher level of improved learning. Teachers undertaking m-learning activities with students in infant school reported significantly lower levels of improved learning.

Concerning the iPAC dimensions, teachers with younger students report significantly lower occurrences of collaboration, personalisation, and authenticity for both respective sub-dimensions. In contrast, teachers undertaking digital learning activities with students in the final stage of primary school reported significantly higher levels of adoption of iPAC-related pedagogies except the agency sub-dimension of personalisation. Similar results emerge for teachers where m-learning takes place outside of the classroom

Table 2
Measurement items (reliability measures and factor loadings).

Independent Variables (iPAC Measures)	Mean	S.D.	% Disagree	% Neutral	% Agree	λ
Collaboration using mobile devices > Conversation (AVE=0.652; CR=0.848; CA=.733)	**2.55~**	**1.08**	**49.4**	**24.1**	**26.5**	**-**
Discussed the work online with their friends/peers e.g. discussed ideas via email, SMS, Skype, Facebook etc.	2.74~	1.40	44.2	25.6	30.2	0.85
Discussed the work online with people they don't know e.g. discussed with a student gamer from other institution, tweeted a NASA scientist, asked question to Brainpop mathematician	2.01~	1.21	65.2	22.7	12.1	0.74
Communicated with others using a variety of text, image, video modes	2.91	1.41	38.8	24.0	37.3	0.83
Collaboration using mobile devices > Co-creation (AVE=0.676; CR=0.861; CA=.756)	**3.15ˆ**	**1.16**	**32.0**	**24.3**	**43.7**	**-**
Worked together to create a digital product e.g. co-created a video, podcast, photo, iBook,	3.30ˆ	1.46	28.8	22.9	48.3	0.85
Shared digital content e.g. shared a video, podcast, photo, document	3.40ˆ	1.38	24.8	24.6	50.6	0.90
Contributed to existing digital content e.g. tagged a photo, commented on a blog post	2.76~	1.41	42.5	25.4	32.1	0.71
Personalisation using mobile devices > Agency (AVE=0.650; CR=0.848; CA=.729)	**2.94**	**1.08**	**36.7**	**27.9**	**35.4**	**-**
Chose the place to do the activity e.g. chose to work on the bus, at home, in the playground	2.85~	1.44	39.1	26.6	34.3	0.82
Determined the pace at which they did the activity	3.10	1.28	31.8	27.9	40.3	0.84
Decided what they wanted to learn e.g. chose own question, problem, project to explore	2.86~	1.29	39.3	29.2	31.5	0.76
Personalisation using mobile devices > Customisation (AVE=.674; CR=.892;CA=.838)	**2.66~**	**1.10**	**44.1**	**26.9**	**29.0**	**-**
Were guided by the app(s) based on their past use e.g. by previous game challenge levels, YouTube recommendations prompted by their previous views	2.72~	1.36	43.0	26.9	30.2	0.80
Tailored app(s) settings to their preferences e.g. customised location on/off, camera/ microphone access, time limit settings	2.91	1.33	36.3	29.3	34.4	0.81
Received individualised information through the app(s) about themselves e.g. information about the number of steps walked, calories eaten, hours slept	2.46~	1.35	50.0	25.8	24.2	0.84
Customised feeds and links for their learning needs e.g. tailored social media or news feeds	2.56~	1.35	47.1	25.8	27.1	0.84
Authenticity using mobile devices > Context (AVE=0.694; CR=0.872; CA=.778)	**2.68~**	**1.15**	**45.7**	**24.8**	**29.6**	**-**
Learned in a place suggested by the topic e.g. learned about stars under the night sky; pollution at a local stream; History at the site of an ancient battle	2.86~	1.45	42.4	21.9	35.7	0.82
Learned in a realistic, virtual space e.g. augmented or virtual reality apps, science simulation	2.55~	1.36	48.3	26.6	25.1	0.81
Learned at a time suggested by the topic e.g. night-time observation of stars; weekend analysis of sporting performance	2.64~	1.35	46.3	25.7	28.0	0.87
Authenticity using mobile devices > Task (AVE=0.656; CR=0.884;CA=.825)	**2.89~**	**1.07**	**37.5**	**28.8**	**33.7**	**-**
Worked like an expert e.g. collected data using GPS like a geographer; measured using an inclinometer app like a scientist; composed music or lyrics to a song like a musician	2.83~	1.38	42.1	25.1	32.8	0.82
Participated in real-world activities that benefit society e.g. citizen science project that included real-life experts; environmental task on waste	2.86~	1.33	38.4	29.3	32.3	0.83
Learned serendipitously in an unplanned way e.g. during a game, research prompted by an unexpected query	2.82~	1.27	37.7	30.9	31.4	0.80
Engaged in activities related to everyday life e.g. developing a budget	3.03	1.30	31.9	29.8	38.4	0.80
Dependent and Mediator Variables	**Mean**	**S.D.**	**% Disagree**	**% Neutral**	**% Agree**	**λ**
Perceived Improved Student M-Learning Outcome (AVE=0.806; CR=0.943; CA=.88)	**3.67ˆ**	**0.83**	**14.1**	**27.6**	**58.3**	**-**
Using mobile devices improved my <year > students' learning in <discipline area>	3.64ˆ	1.16	13.4	29.2	57.4	0.88
My <year level> students enjoyed using mobile devices to learn about <discipline area>	3.87ˆ	1.17	11.7	22.7	65.6	0.91
My <year > students found it difficult learning <discipline> using mobile devices (R)	3.54ˆ	1.17	17.5	30.9	51.7	#
Using mobile devices helped my <year > students to understand concepts in <discipline>	3.59ˆ	1.15	14.1	30.9	55.0	0.90
Using mobile devices helped my <year> students to practise < discipline area > skills	3.71ˆ	1.17	13.6	24.4	62.0	0.90
Innovation in m-learning vs. without mobiles (AVE=.671; CR=.91; CA=.92)	**3.37ˆ**	**0.97**	**21.5**	**31.1**	**47.4**	**-**
Use of a mobile device fundamentally changed the way that learning occurs	3.52ˆ	1.22	18.8	27.2	54.0	0.82
The context of learning was radically different (in terms of setting, time, mode of task)	3.37ˆ	1.18	21.7	31.3	47.0	0.85
The range of stakeholders facilitating learning was greatly expanded (e.g. teachers, family, community members and other experts)	3.07	1.25	31.3	32.4	36.3	0.76
Learners were granted significantly more agency than would normally be the case	3.38ˆ	1.13	19.1	32.4	48.6	0.82
Learners' overall experience was fundamentally different from what they would normally experience in <year level> <discipline area>	3.52ˆ	1.17	16.7	32.4	50.9	0.84

λ = factor loading; AVE = Average Variance Extracted; CR = Composite Reliability; CA=Cronbach's Alpha; # Item not used in factor analysis; (R) = item reverse coded.
ˆ/~ Mean rating is significant above/below neutral rating of '3'.

and for settings where students use their own digital device. In contrast, few significant differences are reported in relation to differences across teachers with contrasting levels of teaching experience or the subject area in which the learning took place.

These differences are accounted for as control variables when evaluating the impact of iPAC dimensions on PISLE and the mediating impact of m-innovation as a mechanism to explain such effects.

4.3. Structural model results

The overarching research question was used as a guide to specify a structural equation model (SEM) utilizing a covariance-based strategy (Hair et al., 2009). We first estimated a total effects model to examine the impact of iPAC sub-dimensions (or digital pedagogies) on PISLE without the mediating impact of m-innovation. Second, the mediator is included detailing how the aforementioned total effects can be equated into a set of indirect (via the mediator, m-innovation) and direct effects (remaining variance explained without the mediator) (see, Baron & Kenny, 1986). This second model thereby addresses the research question by testing whether teachers' perceptions of improved student learning experiences are impacted by their iPAC pedagogical practices via the mediating role of digital pedagogical innovation. The first model results provide a comparison against previous testing of the iPAC Framework, which, until now, have excluded accounting for m-innovation as a mediating variable that explains the process by which iPAC mobile pedagogies impact teachers' perceptions of improved student learning (i.e., PISLE).

4.3.1. Total effects model: impact of iPAC digital pedagogies on PISLE

The total effects model results (i.e., excluding the mediating term, m-innovation) indicate that teachers perceive that their students' learning experiences significantly improve when activities incorporate all but one of the iPAC digital pedagogies (see Table 3). Specifically, variation in the level of student conversation (collaboration sub-dimension) during the digital activity, had no significant impact on PISLE (Est. $c = -0.06$; $p = .322$). At the other extreme, digital activities involving collaboration in the form of greater levels of co-creation (e.g., sharing a document; or making a video) were the largest predictor of PISLE (Est. $c = 0.406$; t = 6.340; $p < .001$). Similarly, greater levels of personalisation (particularly, agency and customisation) and authenticity (particularly context and task) predicted teachers' perceptions of improved student learning experiences. The results support prior literature that when iPAC digital pedagogies are incorporated into tasks, teachers perceive an improvement in student learning experiences.

4.3.2. Impact of iPAC digital pedagogies on levels of M-innovation

The impact of using the iPAC digital pedagogies on m-innovation is considered here. The first stage of the indirect effects model provides estimates of 'a', which capture the impact of any one iPAC sub-dimension on reported levels of m-learning innovation in teachers' nominated activity. The results indicate that m-innovation is perceived as significantly higher by teachers who employed digital activities that foster collaboration in the form of co-creation (Est. $a = 0.320$ t = 5.110; $p < .001$) and higher levels of task authenticity (Est. $a = 0.351$; t = 5.988; $p < .001$). The same conclusion can be reached about personalisation in the form of greater agency and greater customisation, as well as the greater use of authentic contexts ($p < .001$). Only one iPAC dimension was not significant in explaining m-innovation: whether teachers undertook activities where students had lower or higher levels of online conversations. The sub-dimension of conversation had no significant impact on reported levels of m-innovation (Est a = -0.020; $p =$ .750).

4.3.3. Impact of iPAC digital pedagogies on PISLE via M-innovation (test of mediation)

The next stage of the analysis is to consider whether the mediating variable, m-innovation, is significant in explaining variation in levels of PISLE; as noted by the significance of the estimate of 'b' in the structural equation model inclusive of both direct and indirect effects (see Stage 2 estimates in Table 3).

Consistent with the overarching research objective, the full assessment of the mediation model can be considered. To do so, we consider whether the total effects (denoted c) are more significantly explained by the indirect effect of each iPAC sub-dimension on PISLE via the mediator (i.e., estimates of 'ab') relative to the unexplained effects that remain (i.e., the direct effects, denoted by estimates of c'). The estimates of the direct effects and components of the indirect effects are provided in Table 3 and Fig. 3, with a visual representation denoting the size of these effects in Fig. 4.

The test of mediation occurs as follows: examining the size of the combined indirect effect for each corresponding iPAC sub-dimension (i.e., Est. ab, the product of Est. a and Est. b) indicates the presence of significant mediation. If the corresponding direct effect (i.e., Est. c') is insignificant (remains significant) then full (partial) mediation can be concluded (Burke, Eckert, & Sethi, 2020; Baron & Kenny, 1986; Judd & Kenny, 1981).

Full or complete mediation concerning the impact of iPAC sub-dimensions on PISLE via m-innovation occurs for three out of the six dimensions (denoted 'F' in Table 3; $p < .001$): namely, personalisation in the form of agency and customisation, as well as task authenticity. Partial mediation occurs with two of the six iPAC sub-dimensions (denoted 'P' in Table 3). Specifically, while a significant indirect effect on PISLE via m-innovation is reported in relation to authentic context and collaboration in the form of co-creation ($p <$ .001), the presence of significant remaining direct effects ($p < .001$) indicate only partial mediation has occurred. No significant mediation effect occurs in relation to the final iPAC sub-dimension of collaboration in the form of conversations. Specifically, both the indirect effect (Est $ab = -0.009$; $p = .751$) of this dimension and the total effect (Est $c = -0.064$; $p = .322$) are not significant. As such, Fig. 3 shows conversations have a negative direct effect; this is to account for the negative total effect balanced against the positive indirect effect (i.e., $c = ab + c'$). All effects relating to conversations are not significantly different from zero at the 0.05 level; hence, the signs of these effects should not be used for interpretation. Explanations for the lack of significance for this sub-dimension are found in the discussion section.

The results confirm that when teachers fundamentally change how students learn with mobile devices, relative to when the same students undertake learning in the same discipline area without mobile devices, PISLE are significantly improved (Est. $b = 0.471$; t = 6.104; $p < .001$).

4.3.4. Accounting for differences across teachers and activity context

Several control variables were included in the estimated structural model to account for differences across teachers and teaching contexts with respect to the dependent and mediating variables. Concerning the mediating variable, m-innovation, the estimates of a

Table 3
Impact on perceived improvement in student learning (total, direct and indirect effects).

	Variable	Total Effects X => PISL			Indirect Effects (Stage 1) X => MINV			(In)Direct (Stage 2) MINV, X => PISL			Test of Mediation (Indirect Effects)		
		Est. *c*	S.E.		Est. *a*	S.E.		Est. *c'*	S.E.		Est. *ab*	S.E.	
	Intercept	0.069	0.135		0.164	0.132		−0.005	0.128		0.077	0.064	
iPAC Dimensions	**iPAC Sub-Dimension**												
Personalisation	Agency	0.221	0.064	***	0.269	0.064	***	0.096	0.065		0.127	0.036	***F
	Customisation	0.227	0.062	***	0.324	0.061	***	0.077	0.064		0.152	0.038	***F
Authenticity	Context	0.273	0.061	***	0.191	0.060	***	0.185	0.059	***	0.090	0.032	***P
	Task	0.219	0.060	***	0.351	0.059	***	0.055	0.062		0.165	0.039	***F
Collaboration	Conversations	−0.064	0.065		−0.020	0.063		−0.056	0.061		−0.009	0.030	
	Co-creation	0.406	0.064	***	0.320	0.063	***	0.256	0.065	***	0.151	0.038	***P
Mediator:	**M-Innovation (Est. *b*)**	–	–		–	–		0.471	0.077	***	–	–	
Control Variables:		**Est. *c***	**S.E.**		**Est. *a***	**S.E.**		**Est. *c'***	**S.E.**		**Est. *ab***	**S.E.**	
Teacher Experience:	Pre vs. In-service	−0.004	0.073		0.051	0.075		−0.028	0.068		0.024	0.035	
	Years in classroom	−0.033	0.049		−0.008	0.050		−0.029	0.046		−0.004	0.023	
	Using m-devices	−0.004	0.062		0.159	0.064	**	−0.078	0.058		0.074	0.031	**
Activity Location:	In classroom	−0.136	0.095		−0.445	0.098		0.071	0.092		−0.207	0.050	***
	At school, out of room	−0.024	0.091		0.136	0.094		−0.088	0.085		0.063	0.044	
	Educ. setting off-campus	−0.210	0.102	**	−0.006	0.105		−0.207	0.095	**	−0.003	0.049	
	At home	0.284	0.090	***	0.367	0.093		0.113	0.086		0.171	0.047	***F
	At other location	−0.031	0.097		−0.102	0.100		0.016	0.091		−0.048	0.047	
Device Ownership:	Institution (on campus)	0.141	0.074		0.125	0.076		0.083	0.069		0.058	0.036	
	Institution (off-campus)	0.026	0.087		−0.182	0.090	**	0.111	0.082		−0.085	0.043	**
	Student owned	0.078	0.077		0.126	0.080		0.020	0.072		0.059	0.038	
Activity Subject:	English	−0.136	0.073		−0.053	0.075		−0.111	0.068		−0.025	0.035	
	Science	−0.046	0.094		−0.064	0.097		−0.016	0.088		−0.030	0.045	
	Mathematics	0.034	0.110		0.005	0.114		0.032	0.103		0.002	0.053	
	Non-Eng. Language	0.207	0.109		0.110	0.113		0.156	0.102		0.051	0.053	
Activity Year Level:	Stage 1 (K), 1 and 2)	−0.209	0.094	**	−0.043	0.097		−0.189	0.088	**	−0.020	0.045	
	Stage 2 (Yrs 3 & 4)	−0.127	0.100		−0.004	0.103		−0.125	0.093		−0.002	0.048	
	Stage 3 (Yrs 5 & 6)	−0.058	0.108		−0.080	0.111		−0.021	0.101		−0.037	0.052	
	Stage 4 (Yrs 7 & 8)	0.076	0.121		0.085	0.125		0.036	0.113		0.040	0.058	
	Stage 5 (Yrs 9 & 10)	0.015	0.117		−0.047	0.121		0.037	0.110		−0.022	0.056	
	Stage 6 (Yrs 11 & 12)	0.216	0.131		0.142	0.135		0.150	0.122		0.066	0.063	
Region:	Australia or New Zealand	0.089	0.068		−0.039	0.070		0.107	0.064	*	−0.018	0.033	
	Europe	−0.075	0.066		−0.026	0.068		−0.063	0.061		−0.012	0.032	

*/**/*** estimate significant at 0.05/0.01/0.001 level. F/P denotes significant full/partial mediation.

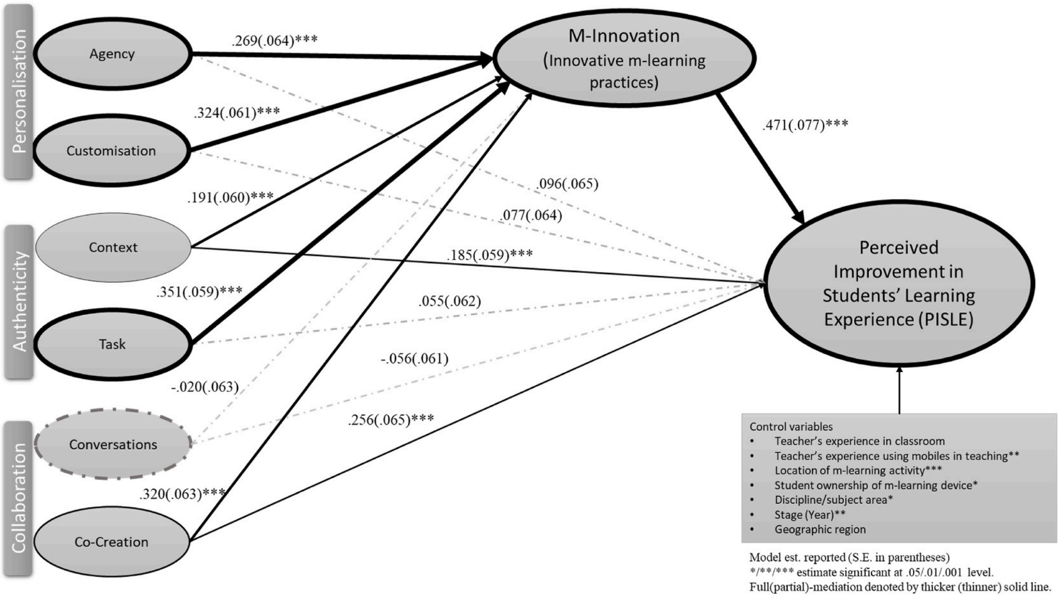

Fig. 3. Estimates of PISLE model.

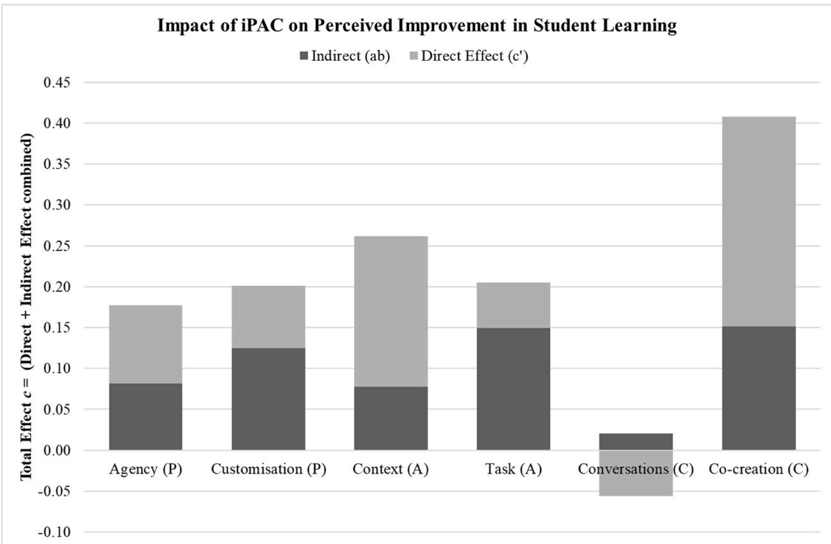

Fig. 4. Impact of iPAC on PISL: Direct, Indirect and Total Effects.

(see Control Variables, Table 3) reveal that fundamental changes to teaching were more significant among teachers that had greater experience in using mobile devices ($p < .01$), but less significant in activities undertaken by students using institution-owned devices that could be used at home or at school ($p < .01$). Overall, PISLE was significantly higher when students undertook learning activities at home ($p < .05$), but significantly lower when the activity took place in an off-campus educational setting (e.g., excursion; museum) ($p < .05$) and with infant school students ($p < .05$).

To summarise, the conceptual model proposing that teachers' use of iPAC digital pedagogies significantly impact overall teachers' perceptions of improved student learning experiences via the mediating impact of m-innovation is fully supported for three iPAC sub-dimensions (agency, customisation, task authenticity) and partially supported for two iPAC sub-dimensions (context, co-creation). The exception is teachers' digital pedagogies supported by the iPAC sub-dimension of student conversation. That is, teachers who implement digital activities with enhanced agency, customisation, and task authenticity are more likely to perceive their task as more innovative which increases their PISLE. The same conclusion can be reached for teachers adopting enhanced context and co-creation digital pedagogies, but the improvement in PISLE is not fully explained by the mediating impact of these two variables on m-innovation. Finally, the adoption of enhanced student conversation in teachers' digital pedagogical designs had no impact on perceptions of m-innovation or PISLE.

5. Discussion

This study contributes to the literature by demonstrating for the first time the impact of five iPAC sub-dimensions on digital pedagogical innovation and the mediating effect of this innovation on PISLE. The results demonstrate how innovation acts as a 'mediator' in helping to predict the learning gains associated with the adoption of the iPAC mobile pedagogies, suggesting that the use of greater agency, customisation, and authenticity create more innovative digital learning opportunities and approaches that can be linked with teachers' perceptions of improved student learning experiences. These findings are significant because they reveal more nuanced and effective approaches to the deployment of digital devices. Several highlights from the research and implications of these are now discussed.

The results of this study show that the iPAC sub-dimensions can be divided into three different groups, depending on the strength of their effects on m-innovation and consequently, PISLE.

The first group comprised three sub-dimensions, agency, customisation, and task authenticity, each of which demonstrated a significant impact on m-innovation and therefore full mediation of m-innovation on PISLE. This suggests that teachers who use these sub-dimensions in their activities will provide more innovative learning experiences which will lead to their perceptions of improved student learning experiences. The strength of these effects suggests the importance of these three approaches in facilitating radically and fundamentally different learning to that occurring without the use of mobile technologies. The findings suggest that the use of m-learning devices is innovative by providing greater opportunities for students in terms of their ability to choose where, how, and when they learn, as well as to receive individualised guidance tailored to each student's needs and performance. This finding is supported by other studies that suggest that innovative learning, seen as e-learning, agile learning and blended learning supports the ability to learn anywhere and at any time and this leads to effectiveness in learning (Lee et al., 2024; Topping et al., 2022). For teachers, the implication is that their selection of m-learning tasks should be guided by whether such tasks (including their choice of which 'apps' to select for students to use) foster personalisation and that they should avoid those that do not provide feedback to students or do not allow students greater autonomy in their time, pace and place of learning.

In terms of task authenticity, these findings suggest that there are greater opportunities for innovative learning experiences when students are encouraged to work like experts and undertake activities that are related to everyday life, including those that offer benefit to society, such as citizen science projects. This also reinforces previous research that values m-learning tasks that can be created for students to think and work like experts, such as acting like scientists and supporting an inquiry process (e.g., Khoo & Otrel-Cass, 2017; Lowell & Tagare, 2023). Consequently, teachers wishing to create greater forms of m-innovation should focus their attention on whether their m-learning activities promote their students' abilities to work like experts.

The second group comprised two iPAC sub-dimensions, authentic context and co-creation. These sub-dimensions had a partial effect on PISLE through the mediation of m-innovation. This suggests that teachers who use these sub-dimensions in their teaching can explain some of their effect on PISLE by providing innovative tasks, but this is only a partial mediating effect. In other words, the PISLE is partially due to the mediating effect of m-innovation, but m-innovation does not explain the whole effect of these sub-dimensions of iPAC on PISLE. It is possible that teachers did not believe these sub-dimensions were as innovative in their teaching as the first three sub-dimensions because they were common features of their digital teaching. Nevertheless, it is clear that authentic contexts and co-creation were responsible for perceptions of improved learning. This finding is supported by research arguing for the value of co-creation in improving student learning, alongside innovation in teaching, and which suggests that innovation must be harmonised with technological pedagogies (Quaicoe et al., 2023). In the current study, this harmonisation is evidenced by the partial mediation of m-innovation.

Finally, the last group has one sub-dimension, conversation which showed no significant mediating effect of m-innovation on PISLE. This finding that increased levels of student conversation is not a significant driver in terms of creating perceptions of m-innovation warrants attention. Several possible explanations for these findings may be offered although each requires further research and investigation.

In the iPAC Framework, student conversation is one of two sub-dimensions under the Collaboration dimension which focuses on how student learners use their mobile devices to make rich connections to other people and resources (Fu & Hwang, 2018; Lowell & Tagare, 2023). This includes the ability to use a mobile device to share content and to create shared, social interactive environments through, for example, a *WhatsApp* group or *Instagram*. The present results reinforce Zydney et al.'s (2016) recommendation – following their review of mobile apps for science learning – that there exist more innovative approaches and strategies that encourage using mobile apps for collaboration. Furthermore, while it is entirely feasible to undertake conversational activities in a face-to-face environment during a mobile learning task (e.g. in a classroom), the survey questions relating to the conversation sub-dimension focus mainly on students' virtual and distance conversations (see Burden, Kearney, Schuck, & Hall, 2019).

A further consideration around the result relating to conversation emerging from this study is that in all three survey questions, respondents are asked to consider how frequently their students used a variety of online platforms such as SMS, e-mail, and video-conference facilities to discuss their work with a variety of different audiences. Hence, one explanation of the result is that some of these applications and tools may be dated and therefore infrequently used by young people today. Young people instead use online platforms (e.g., *TikTok; Instagram*) to share a huge volume of digital content, both curated and created by themselves (Jimola, 2023). Such digital content, however, is seldom, if ever, created in response to teachers' requests. There is an ever-present concern among schoolteachers around cybersecurity, privacy, and online predators. This may reflect their concerns about the use of these specific types of online activities or may even be prohibited by school rules and procedures, particularly those relating to students' use of online channels to discuss their work with strangers or persons external to the school network.

The findings encourage teachers to promote collaboration that goes beyond online discussions among students, in a way that leads to student-led co-creation and sharing of digital content (e.g., videos, podcasts, documents). They also indicate that students' technology-based interactions and technology-led constructions are complex constructs with multiple aspects that may be important to further distinguish and describe from both an empirical and nomological perspective (Antonietti et al., 2023).

Of note and perhaps concern are the actual rates of adoption of iPAC pedagogical approaches among teachers: teachers indicated significant rates of disagreement that they employed m-learning activities that involve personalisation and authenticity – and their respective sub-dimensions – along with collaboration in the form of student conversations undertaken online. One exception to this result is that teachers reported higher rates of agreement that their students were undertaking collaboration in the form of co-creation activities, where students work together to create or share digital content.

The explanation for why such low rates of iPAC pedagogical characteristics in teaching are observed remains elusive; several explanations may be offered. For example, teachers may see these elements as a distraction to student learning (Bartholomew & Reeve, 2018; Fabian et al., 2016; Gimena et al., 2023) or might experience a variety of school-based challenges (Quaicoe et al., 2023; Rodriguez-Segura, 2020). In other cases, issues of resources and policies for students inside and outside the classroom to undertake appropriate m-learning activities may arise (Lindberg Ola, 2017; Nikolopoulou et al., 2023). Another barrier to a more widespread adoption of iPAC elements in m-learning could be the lack of teacher confidence or efficacy (Nikolopoulou et al., 2023), as well as related technical issues encountered in the use of such technologies (Abdulrahim & Bolaji, 2024; Lai et al., 2016; Tondeur et al., 2017). Teachers may also be concerned about students' abilities and confidence with technology (Wang et al., 2023; Zhai et al., 2018). A final barrier may simply be the lack of awareness or knowledge about appropriate externally derived resources (e.g., a range of apps) that could meet teachers' desires to appropriately incorporate pedagogy for student learning (Ertmer et al., 2012; Quaicoe et al., 2023; Zydney & Warner, 2016). In any case, the findings point to a need for research to understand the factors behind such low rates of adoption.

Several limitations of the study are worthy of highlighting. In relation to the measures, the teachers self-reported on their own perceptions of improved student learning rather than relying on other outcomes, such as student assessment performance. Further, teachers were asked to focus on a task designed and facilitated by the teacher rather than examples of radical innovations that had been sourced from students or their community (Burden, Kearney, Schuck, & Hall, 2019; Jimola, 2023). A further limitation is that related to the potential introduction of bias from sample self-selection: some participants may have chosen to participate or complete the survey in its entirety because of a greater interest in innovative digital pedagogy relative to other teachers. Control variables relating to efficacy in the use of mobile devices in teaching attempted to account for such effects. There may also be sampling limitations owing to the graphical representation. Further, the research failed to include early childhood or tertiary education settings in the sampling frame.

Future research could investigate several elements unanswered by the present research. For example, the reasons for the powerful mediating effect of three digital pedagogies (agency, customisation, and task authenticity) on innovation remain open to speculation. Further research should investigate why this effect occurs. Similarly, we do not have data explaining the partial effect of context and co-creation and future research would be valuable in explaining this. As a guide for teachers, a set of empirical examples of innovative practice based on iPAC digital pedagogies are available from https://www.ipacmobilepedagogy.com to assist in improving student learning experiences. However, there is a need to determine a way of linking teacher perceptions of improved student learning experiences with student learning outcomes, to gain a deeper understanding of technology-mediated learning. Another fruitful area for future research is regarding the iPAC sub-dimension of conversation. An exploration of the interplay between the various forms of student conversation (online or face-to-face) and digital innovation would be valuable. In addition, the importance of the school culture in supporting teachers to undertake innovation in using digital approaches is worthy of consideration (Ninković et al., 2023).

Further questions around teachers' engagement and efforts to realise student' learning through mobile learning could also be considered in subsequent studies. That is, our research is unclear about whether teachers, who are able to realise greater benefits by undertaking innovative digital learning pedagogies, will respond and be motivated to engage with their practices more deeply and will undertake greater effort to invest in innovative practices consistent with iPAC pedagogical practices. Indeed, for some teachers, such an investment in pedagogical innovation may be difficult without proper support and training to do so (Aubusson et al., 2014; Schmitz et al., 2022). For example, our results indicate that changes in pedagogy leading to m-innovation were more significant among teachers who had greater experience in using mobile devices. Hence, further research into the barriers and accompanying solutions to innovative digital pedagogy are likely to offer worthwhile insights to extend the current work. As noted in prior literature, such barriers and interventions required are likely to arise from a wide variety of sources, including factors relating to individual teachers, students, organisational factors, and the digital technologies themselves (e.g., Makki et al., 2018; Ninković et al., 2023; Schmitz et al., 2022; Schulz et al., 2015).

6. Conclusion

In previous research, the value and impact of the iPAC Framework in terms of teachers' pedagogical actions and perceptions of improved student learning experiences have been demonstrated in several contexts (e.g., Kearney et al., 2019; Kearney, et al., 2023). However, this paper breaks new ground in exploring how innovation mediates the impact of dimensions of the iPAC Framework to provide perceived improvements in student learning experiences (PISLE). In many previous studies, innovation has been treated somewhat superficially, with an unproven assumption that it improves perceived student learning experiences. In this piece of research, we have used structural equation modelling, which although not an original methodology in itself, has not been used previously to understand the mediating role of innovation on digital pedagogies and their impact on perceived student learning experiences. Combined with the rigour created using a large worldwide sample and ensuring that all constructs in the survey were tested for reliability and validity, the research approach has been able to generate findings and claims that transcend traditional small-scale case study research commonly undertaken in the field.

The study highlights the importance of personalised learning and realistic tasks in teachers' perceptions of innovation and improved learning experiences. Teachers place a high value on learner agency and experiences tailored to individuals, as well as relevant tasks, and they see these approaches as transformational to students' experiences. The study contributes new insights as to how innovation can mediate digital mobile pedagogies and lead to perceptions of improved learning experiences. The article goes beyond a rhetorical narrative of innovation that presents innovation as a benefit and provides an evidence base to support the value of innovative practice in digital mobile pedagogies. The findings presented in this article will be helpful and informative to teachers and researchers in identifying and implementing innovative digital mobile pedagogies that lead to teachers' perceptions of improved student learning experiences.

CRediT authorship contribution statement

Paul F. Burke: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sandy Schuck:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Kevin Burden:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Matthew Kearney:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization.

Data availability

Data will be made available on request.

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