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Twelve years of iPads and apps in schools: What conditions support effective practices in K-6 classrooms?

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Since their release in 2010, iPads and their associated apps have been touted as 'game changers' for schools struggling with technology provisioning issues, that limited their ability to fully leverage the educational potential of digital devices on a 'whole class' basis. Since then, a variety of schemes have been implemented such as 'Bring Your Own Device' (BYOD) and portable 'device pods', as systems for improving access to, and utilisation of, mobile technologies in classroom curriculum. In many schools, concurrent to these initiatives have been improvements in technology infrastructure, including upgrades to external connectivity via the advent of high-speed fibre-based broadband, and internally through the establishment of school wifi networks and associated online security systems. Aligned with these developments has been a growing body of research exploring how teachers at all levels of education systems have incorporated these new resources into their curriculum, and examining what, if any, benefits have resulted. This article is an analysis of key findings from four published studies undertaken by the author between 2015 and 2021 in New Zealand K-6 schools, to build understanding of factors that contributed to the effective practices with mobile devices witnessed in the research classrooms. While numerous separate studies have been undertaken exploring specific outcomes from the use of iPads and other mobile technologies in different educational contexts, the analysis presented in this article attempts to identify common factors existing across four purposively selected studies, that contributed to their success. The studies were deliberately chosen to provide a broad overview of applications of this technology in different K-6 classrooms for different purposes, supporting deeper understanding of the factors that underpin effective teaching and learning with and through mobile devices, in schools. This is important, as it builds knowledge of the fundamental foundations to effective educational use of mobile devices, regardless of the learning context in which they are used, and could assist teachers in designing, implementing and assessing curricular that optimises the learning potential of these devices.

KEYWORDS

iPad, apps, K-6, curriculum, pedagogy, collaborative learning, simulations, digital literacy

1. Introduction

Education has a long history of rapid adoption of technological innovations, on the expectation that their use in classrooms will catalyse significant improvements in students' learning. However, according to Blackwell et al. (2013), "previous promises of a technological revolution in education have failed to produce much change [and] despite increased access to computers and newer mobile devices, the actual use of technology in the classroom remains infrequent, especially in early childhood education" (p. 310). Some research points to historical technology provisioning challenges, while other work identifies issues with teacher pedagogy and dated learning and curriculum designs, "which follow a production-line mentality, with conformity and standardisation at the heart of it" (Moreau, 2018, p. 8). This article presents an analysis of key findings from four studies undertaken by the author between 2015 and 2021, investigating factors that contributed to and sustained the effective practices of teachers using iPads in junior primary (elementary) school classrooms in New Zealand. The analysis unpacks the relationship existing between teachers' theoretical understandings about learning processes, their associated classroom curriculum design and pedagogy, student capability, and school leadership, in helping establish learning environments optimising and sustaining benefits from 'whole class' iPad access. The detailed, 'fine-grained' methods used in all investigations enabled highly authentic data to be collected and analysed, that arguably presented an accurate account of the students' practices with, and outcomes from, seamless access and use of iPads in their learning programs-and the broader environmental and teacher-related factors that facilitated these.

Findings highlighted the critical importance of teachers' theoretical understandings about how learning occurs, and the type of future knowledge and skills their students need, as the cornerstones of their high performing, digitally-enhanced learning environments. Theoretical understandings generally aligned with constructivist perspectives, and reflected in pedagogies and curriculum that maximised the affordances of full class access to the devices. This was supported by wider school environmental factors such as principal leadership, that shared a similar perspective and prioritised decisions that were supportive of furthering students' and teachers' digital practices. These manifested in classroom environments that were high performing, innovative, and future-focused.

2. Research significance and goal

While numerous studies have been completed exploring the use of mobile devices for specific learning purposes, this analysis attempts to identify common factors that contributed to successful iPad use for *four different learning purposes*. The four studies were purposively selected as they reported on use that was targeted at very different social and academic outcomes. These included using apps as scaffolds for learning basic science concepts, for supporting general and computational thinking capabilities, accessing and working with online information, and for fostering collaborative learning. The selection of these particular studies was deliberate, as they supported a more broadly-based evaluation of 'iPad-supportive' pedagogies, curriculum and classroom and school environments. Moreover, while individual studies of how these devices can 'add value' to learning are relevant, of equal relevance is determining and understanding any factors or conditions they might have *in common*, that contributed to their success. This knowledge is important, as it can provide insights into more general and possibly transferable factors and considerations underpinning effective device use, irrespective of the learning purpose to which they are applied. This will also help guide teachers, by informing them of particular aspects of their pedagogy, curriculum and/or classroom practice that may need reconceptualising, to improve outcomes from increasingly ubiquitous access to mobile devices in their classrooms. Therefore, the questions guiding analysis of the studies were:

1. What, if any, commonalities existed across the four selected studies that provide insights into the foundations of effective iPad use in the classrooms?
2. How did these combine in forming the effective, digitally-enhanced teaching practices evident in the classrooms?

3. A review of literature

The advent of mobile digital devices such as iPads into schools in many countries, has been described by Geist (2011) as a 'gamechanger' for teachers. He commented that "even with preschool children, apps are unquestionably a new medium for providing educational content [and that] the academic community should pay attention to apps as an important potential factor in children's mobile learning" (p. 760). However, significant recent research has indicated mixed outcomes from their use in classrooms, particularly with younger children who lack mastery of basic skills across general literacy domains (e.g., Christ et al., 2019) or in specific areas such as phonics (Lee, 2016) or reading comprehension (Lenhard et al., 2017; Richter and Courage, 2017). Following an extensive systematic review of studies, Eutsler et al. (2020) commented that very few large scale or quasi-experimental studies have been undertaken that would arguably provide a clearer indication of the learning 'value-added' by mobile devices. Related to this, they claim that of those that have been completed, "three quarters contained a sample size of less than 100 participants… [making it] difficult to gauge the reliability of the quantitative analysis" (p. 1761). Furthermore, Eutsler et al. (2020) identified an inherent weakness in the reviewed studies, with only just over one third indicating use of a theoretical framework or model to help build understanding from the findings. They lamented that this lack of theoretical rigour is impeding research that would "develop a more nuanced understanding of teaching literacy with mobile technologies" (p. 1761), and that researchers need to pay greater attention to theoretical referents to help better conceptualise the processes educators and teachers adopt when integrating technology into their learning programs.

Concerns about the lack of theoretical foundation to educational decision-making and the uncritical uptake and implementation of technology in schools, has a long history. Back in 1986, Cleborne Maddux, in his 'Computers in the Schools' article, *The Educational Computing Backlash,* coined the term 'pendulum syndrome' to describe this phenomenon. In a more recent article in relation to educational technology, he and Rhoda Cummings describe this as:

> … a phenomenon [that] begins with unrealistically optimistic claims and expectations for each emerging educational innovation followed by too-hasty, wide adoption in schools. Inevitably the innovation fails to live up to the initial, over-inflated expectations, resulting in disillusionment and abandonment by teachers, parents and policy-makers… the cycle then begins anew with the

> next fashionable innovation (Maddux and Cummings, 2004, p. 512).

They comment that this phenomenon leads to successive cycles of educational 'fads', where technology innovations are adopted simply "because they are there" (p. 523), rather than because they have demonstrated any particular educational value. They attribute this to both a failure of researchers to effectively communicate findings of efficacy studies to those responsible for implementation, and also to the lack of theoretical foundations to studies, "that provide us with guidelines that have a good probability of resulting in educational benefits of some kind" (Maddux and Cummings, 2004, p. 523). While over 35 years have passed since Maddux's first publication, as Eutsler et al. (2020) identifies, little appears to have changed.

More recently, fears have also been raised by some researchers (e.g., Boon et al., 2021) about the overuse of tablet devices by young children, given the important relationship existing between fine motor skills, cognitive development, executive functioning, and literacy and mathematics outcomes and reasoning ability (Grissmer et al., 2010; Cameron et al., 2016). According to Boon et al., nearly half of a typical school child's day involves exercising fine motor skills in some way – such as through writing, cutting, colouring and so on, but little is known about the effects of substituting some or most of these activities with tablet-based experiences. Given "there is strong evidence of robust connections between fine motor measures and reading measures that include both word decoding and vocabulary" (Boon et al., 2021, p. 527), the lack of rigorous studies examining such questions they claim is problematic. Countering these concerns, strong evidence exists suggesting well planned and targeted use of iPads and other touch screen devices can yield beneficial educational outcomes in varied contexts, including mathematics learning (e.g., Litster et al., 2019); understanding science concepts (e.g., Fokides et al., 2020); and augmenting creative and expressive arts education (e.g., Burnett et al., 2020).

Litster et al.'s interesting 2019 study using qualitative, video data-based methods, investigated kindergarteners' use of virtual manipulative blocks to learn base 10 place and total values. It highlighted the effectiveness of the interactive and simultaneous linking feedback features embedded in their selected app, that provided the young students with formative prompts that effectively guided their independent learning. Furthermore, they identified benefits from what they termed "focused constraint" (Litster et al., 2019, p. 356) app features that effectively placed parameters around students' inputs, and provided audio and or/visual cues and guidance if students exceeded these. While the study concluded these features were generally valuable and effective for verification of answers, self-correction, and/or for stimulating personal verbal connection with, or reflection on, the results of their inputs, it also indicated students' responses to focused constraints was variable. The authors concluded that a combination of existing mathematics and technology knowledge affected the students' capacity to take advantage of the embedded app affordances, and recognise how the 'focused constraints' could be used as scaffolds to guide their responses. In this respect they identified the important role teachers have in fostering students' reflective practices, in order to optimise the learning potential of apps of this nature.

In another study using quasi-experimental methods, Fokides et al. (2020) explored the effectiveness of tablet-based apps for addressing 11 and 12 year old students' misconceptions about plants – in particular, alternative views they held about plant reproduction, nutrition, photosynthesis, respiration and transpiration. They compared declarative and procedural knowledge outcomes from five matched groups comprising:

> Group 1: a control group using conventional 'lecture' and books;
> Group 2: a group taught using constructivist-based '5Es' pedagogy and books;
> Group 3: a group taught using constructivist '5Es' pedagogy and laptops and webpages;
> Group 4: a group taught using constructivist '5Es' pedagogy and tablets (teacher developed apps);
> Group 5: a group taught using constructivist '5Es' pedagogy and tablets (commercial apps).

Using pre-post test methods, the researchers concluded "the advancement of student performance was impressive [for the constructivist groups] and it became striking in the case of laptops and tablets" (Fokides et al., 2020, p. 641). However, results indicated students in group 3 (using laptops and webpages) did not perform as well as those using the tablets, possibly due to advantages derived from the more interactive nature of apps, and benefits from using the haptic touch screen interface to access and manipulate information (Fokides et al., 2020). They also commented that interaction and communication between students in the tablet-based groups was higher than in the other arrangements, suggesting this may also have been a factor supporting their superior performance. Interestingly, delayed post-tests also indicated learning 'slippage' had occurred across all groups. While this was less for the tablet and laptop groups, there was still evidence of regression in understanding of the plant concepts, reinforcing previous science education research indicating the challenges faced in dislodging misconceptions, in what many students perceive as a 'difficult-to-learn' subject (Fokides et al., 2020).

The goal of a quite different study undertaken by Burnett et al. (2020) with 7–9 year olds in England, was to understand "what 'appropriate' [iPad] technology use might look like in participatory theatre," and learn if and how they might be used to "respond to unexpected pedagogical possibilities" (Burnett et al., 2020, p. 205). It particularly explored how the children used the device's video and audio recorder to document events as they organised, prepared and rehearsed their presentations, and how this use evolved responding to new and unexpected opportunities and directions. Qualitative data were collected through detailed student observations while working and via conversations and informal interviews, to understand how they used the devices, and their reasons for doing so. Findings highlighted the value of recordings made on the iPads for revealing students' processes of *narrative creation,* which traditionally occurred in isolation or without teacher presence, but could be made public and shared *via* the recordings. They also indicated enhanced creative outcomes from using the device to record private *video diaries*, which the researchers argued "opened out opportunities for children to share personal narratives that did not have to be made public or fully conform to the shared storyline" (p. 211). Feedback reports that supported different modes of participation were also created by some students using the recorder. These adopted different formats with some following conventional 'presenting back' styles, while others resembled television documentaries in which students role played presenters and participants. Across all uses, the researchers commented on how the device's display acted as a focal point for students' attention, and thus helped build a sense of collaboration or *togetherness* by creating a shared space in which they could reflect on and evaluate their efforts. This finding is consistent with earlier research that signals beneficial outcomes from iPad use for supporting learning collaboration (e.g., Falloon, 2015; Kuo and Kuo, 2020).

However, while the previously detailed studies conducted in different contexts and utilising different methodologies and measures yielded generally positive outcomes, as Geer et al. (2017) point out, the mere inclusion of iPads into any educational context does not necessarily lead to improved outcomes. From their analysis of the 'iPad-supported' practices of teachers in Australian schools, they comment that "it is how teachers implement and integrate these technologies into their teaching, that will determine their impact on learning" (p. 491). They suggest that fundamental pedagogical changes are needed that transition curriculum toward more student-oriented approaches, and engage authentic, 'real world' learning contexts where mobile technologies can support new types of teaching and learning. Their analysis of the most effective practices indicated iPads supported this transition in four key areas: enhanced collaboration; improved communication; greater student self-reliance/autonomy, and increased engagement through access to more relevant, 'real-world' information and learning opportunities. However, Geer et al. commented on the challenging nature of this transition for many teachers, pointing out that while potential exists for mobile devices such as iPads to help facilitate new teaching approaches better aligned with desired '21st Century' learning outcomes, "best practice is not evident as yet" (p. 497).

4. Research design

4.1. The selected studies

Four studies were purposively selected for this analysis, specifically as they focused both on student outcomes, and also on the teaching practices and curriculum that facilitated them. The studies took place in two K-6 (primary) schools located in the Waikato region of New Zealand and involved over 200 students and 9 teachers from 6 different classrooms. The schools were mid decile (i.e., in mixed socio-economic locations), with roles of over 500 and student populations comprising approximately 20% New Zealand Maori, 20% Asian, 50% New Zealand European and 10% other ethnicities. The ethnic balance of students in the classrooms in which the studies were completed was generally reflective of the school populations, and they comprised students of average to slightly above average achievement, as judged by the classroom teachers. All studies were approved by the researcher's University Human Research Ethics Committee.

The studies were chosen as they represented quite different uses of iPads to support learning in a range of subjects, they all involved young students (pre K-6), and they were all published in high quality, peer reviewed journals. The studies were:

What's the difference: Learning collaboratively using iPads in conventional classrooms (Computers and Education, 2015);

An analysis of young students' thinking when completing basic coding tasks using Scratch Jnr on the iPad (Journal of Computer-Assisted Learning, 2016);

Using simulations to teach young students science concepts: An experiential learning theoretical analysis (Computers and Education, 2019);

Can they do it? Exploring young students' Technoliteracy in online research (Unpublished manuscript, 2023).[1]

Additionally, all studies used the same iPad display recording system to capture highly authentic video and audio data of students using the devices within regular classroom curricular. Using this system made it possible to record continuous data irrespective of where, and with whom in the large, flexible learning spaces, the students chose to work. Display capture data were also supplemented by classroom observations, teacher and student surveys, interviews and focus groups, and video stimulated recall interviews (VSR). Display capture data were timeline coded using either Studiocode or V-Note Pro video analysis software, with different analysis frameworks being used according to the focus of the study. Figure 1 illustrates a sample V-Note timeline generated from display recorder data from the fourth study.

4.2. Analysis method

Original data from the four studies were accessed and re-coded to identify any similarities in the characteristics of each environment that contributed to their success. More specifically, interview, focus group, classroom observations and survey data were inductively re-coded to build understanding of the teachers' pedagogy and its theoretical foundations, the capabilities of students and teachers' expectations of them, and the nature of school leadership supporting their practices. Data for each were evaluated to determine the contribution they made to establishing the high performing, digitally-enhanced teaching and learning environments within which each of the studies took place.

The four themes (i.e., teachers' theoretical understandings, pedagogy, school leadership and students' abilities/teacher expectations) emerged from the original studies as common elements impacting upon the planning and implementation of the iPad-supported learning units in the classrooms that were researched. A research assistant imported the original code books for each study into NVivo, and completed a keyword/synonym and phrase interrogation of each using search terms aligned with the themes, to identify excerpts across the datasets that defined their characteristics or provided evidence of any similarities that existed. These were manually checked by the author and several adjustments were made to classifications and data added or removed, after negotiation. Following this, the data 'bundles' aligned with each theme were reviewed by the assistant and the author working together, to identify any cross overs between classifications, that suggested possible relationships might exist. This was particularly apparent between data coded under the 'theoretical understandings', 'pedagogy' and 'teacher expectation' themes, suggesting relationships existed between these classifications. These instances were colour coded for later reference, and log notes taken describing the relationship. In the final coding stage, data excepts aligned with each classification were manually evaluated to identify sub themes existing across the datasets. Word constraints

1 The Online Learning Journal (in review)..

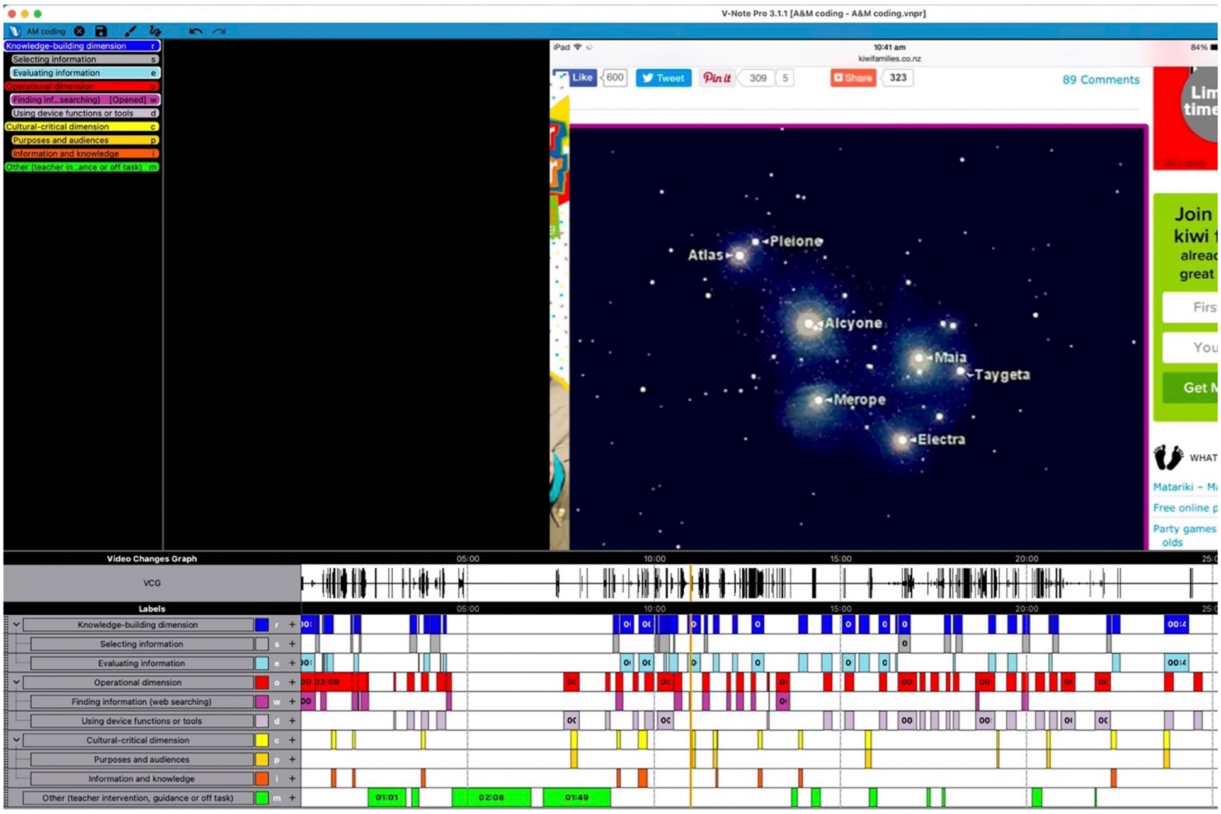

FIGURE 1
Sample V-Note Pro timeline generated from screen recorded data in study 4.

limit significant elaboration here, but a short summary and definition of first level themes and subcodes is recorded in Table 1.[2]

For convenience, the following section provides a brief overview of the selected studies.

5. An overview of the selected studies

5.1. Study 1: What's the difference: Learning collaboratively using iPads in conventional classrooms (Computers and Education, 2015)

This study drew on the early work of Zurita and Nussbaum (2004), examining the physical and technological features and affordances of iPads for supporting collaborative learning in large, multi-class, year 5 and 6 flexible learning spaces in two New Zealand primary schools. It identified several device design features that enabled students to work collaboratively either face-to-face, or in different locations. These included: screen rotation and wide viewing angle; size and weight meaning the device can be easily passed around group members or shared between groups; multi-user accessible interface; and portability, enabling students to work in public or private workspaces. Additionally, the study identified several technical and app-related qualities of the devices that enhanced virtual collaboration, allowing the students to work together from home or other out-of-school locations. These mainly related to use of cloud services such as Google Classroom and Google apps, the use of which was frequently integrated into units of learning. Data from the study indicated the availability of these services enabled real-time collaboration *within* and *beyond* the classroom, with students commenting on improved work accuracy and efficiency through being able to access feedback and share knowledge and ideas to help solve learning problems, as and when needed. Students also identified device advantages for work quality, including the range of apps available to support different aspects of their work allowing them to represent learning in different ways, and app tools such as grammar and spelling checkers and thesauruses, that helped improve the accuracy of written work.

5.2. Study 2: An analysis of young students' thinking when completing basic coding tasks using scratch Jnr on the iPad (Journal of Computer-Assisted Learning, 2016)

Coding is becoming increasingly common in schools worldwide, responding to calls for improved digital capabilities in school leavers who are willing and able to contribute productively to technology businesses and industries, and as a general capability supporting systematic approaches to problem solving. Recent research indicates

2 Examples of coded data can be found in the published articles.

TABLE 1 First level themes, subcodes and definitions/descriptions.

First level theme (classification)	Sub themes	Definition/details
Teachers' theories (beliefs about how students learn, and types of future capabilities they need).	Knowledge	The dynamic nature of knowledge – knowledge development as a social and constructive process (constructivist-oriented).
	Skills	Alignment with '21st Century' skillsets (e.g., collaborative, analytical and critical thinking, ill-structured problem solving, leadership).
	Dispositions/attitudes	Alignment with '21st Century dispositions (e.g., resilience, perseverance, motivation, self-efficacy, independent/self-determining, flexibility).
Teachers' pedagogies (how the curriculum should be taught, and why).	Guided and structured	Guided inquiry-based instructional methods are augmented by more formal, structured approaches where specific knowledge or skills are needed.
	Problem-based	Emphasis is on using devices to access and develop knowledge from information linked to 'real world' problems or scenarios.
	Collaborative	Team and group work is prioritised in project-based curriculum.
	'Consume to create'	Devices used to access and process information (consume) to produce personal digital artefacts (create).
	Blended	Teaching methods, approaches and resources are selected on a 'fit for purpose' basis, according to desired outcome or identified need.
	Metacognitive	Focus on higher order thinking. Students analyse, evaluate, and synthesise information to create original knowledge artefacts.
	Interrogative	Consistently high teacher expectations and required standard of students' work. Students expected to explain and justify features of, and learning processes involved in creating knowledge artefacts.
School leadership (school leadership qualities and attributes impacting upon digitally-enhanced teaching and learning).	Educational vision and purpose	Principal and senior leadership's views of the role and purpose of schools in helping prepare young people for their future. This reflected understanding of the importance of both academic knowledge and '21st Century' competency outcomes.
	Priorities	Decisions made relating to curriculum changes, funding allocations and school upgrades (etc) prioritised improving digitally-enhanced teaching and learning.
	Commitment	School leadership displayed strong and consistent support for staff who were prepared to innovate and implement new approaches in their teaching.
	Distributed style	Leadership of change initiatives and other innovations is shared with staff directly responsible for their implementation.
	Support of innovation	School leadership encourages and supports managed risk taking and innovation.
Students' abilities and teachers' expectations (teachers' belief in their students' capacity to achieve to the best of their ability, and expectation that they do so).	Digital capabilities	Teaching methods and curriculum maximise opportunities for students to exercise and build their digital skills.
	Thinking capabilities	Teaching methods and curriculum maximise opportunities for students to exercise and build higher order thinking skills.
	Creative capabilities	Teaching methods and curriculum encourage diverse outcomes and different ways of achieving these.
	Collaborative capabilities	Teamwork and group collaborative skills and strategies are taught and are expected to be used by students.
	Dispositions	Teachers foster resilience, perseverance, initiative, and independence, and incorporate opportunities to build and exercise these in curriculum.
	Responsible and accountable	Students are accountable and responsible for their learning (work output, quality, and ways of working).

the importance of early years education to establishing positive attitudes and interest in STEM learning (e.g., Samara et al., 2018) and for developing basic computational thinking skills that some identify as an important future competence (e.g., Wing, 2006). This study analysed screen recorded data of 5 year olds using iPads and the Scratch Jnr. app, to solve basic mathematics geometric shape coding challenges set by their teachers (Falloon, 2016). The challenges required students to author procedures in the app to program the Scratch cat to draw a range of geometric and other shapes such as squares, rectangles and upper and lower case letters. Data analysis focused on the levels of thinking students applied to solving the coding problems, and also evaluated the extent to which their understandings and behaviours aligned with Brennan and Resnick's (2012) computational thinking concepts (e.g., sequencing, loops, events) and perspectives (i.e., connecting, questioning, conceptualising, creating, expressing). Findings indicated the problem-based coding tasks provided a highly effective and motivating context through which students could practice a range of computational and general thinking skills at all levels of Krathwohl's (2002) revision of Bloom's Taxonomy (cognitive domain), but particularly those requiring higher level cognitive functioning such as knowledge application, analysis and evaluation, that were generally associated with computational thinking processes.

In addition, the teacher's pedagogical emphasis on learning experiences that fostered students' collaboration and social skills, contributed to an integrated curriculum that included oral language development opportunities through structured components focused on effective methods for giving and receiving feedback, and presenting and explaining their work processes and outcomes to others (Figures 2, 3).

Formative and summative assessment information was collected by recording successfully completed challenges on the class whiteboard, using the students' name initials. Students who were early finishers were then encouraged to provide assistance to others.

5.3. Study 3: Using simulations to teaching young students science concepts: An experiential learning analysis (Computers and Education, 2019)

The third study was somewhat different in nature, as it focused on using app-based simulations for teaching basic science concepts (Falloon, 2019). The research investigated whether simple electrical circuit-building simulations could help 5 and 6 year olds learn basic circuit concepts and the function of circuit components, such as switches, cells, wires and resistors (bulbs, animated toys etc.). A series of four simulations were used, starting with a templated simulation in which students built series and parallel circuits using different components from a component library, following 'snap to' circuit designs provided in the app. This was followed by two, open-ended breadboard apps, both of which provided a drag-and-drop component library and a grid with connection points, for students to build circuits of their own design. The final app was more complex and was only used by 2 of the 38 participating students. This simulation involved constructing different parallel and series circuits from drawings comprising only schematics and component symbols. It was used to extend two students who demonstrated advanced understanding and capability when using the breadboard apps. Similar to the previous study, the curriculum was designed using problem-based pedagogy, where students were presented with several 'Can You…' challenges to build circuits of different designs, using the breadboards and component libraries (see Figure 4). Initial scaffolding was provided through listing only the components and the number needed to successfully complete each challenge.

Teacher input during lessons was restricted to asking open questions and providing oral prompts to guide students' thinking (Figure 4).

Display recorded data were analysed using a coding framework based on a revision of Kolb's (1984) Experiential Learning Theory. Experiential Learning Theory proved a useful referent to help understand how students interacted with the simulations, and built, and sometimes transferred, basic procedural and conceptual knowledge from them. Findings overall were mixed, with almost all students demonstrating some knowledge of basic concepts such as operating circuits needing to be closed and the role of switches in controlling current, but less understanding of more abstract concepts about current pathways in circuits of different designs, and resistance. Additionally, although much evidence was present of students reflecting on observations about the results of their trials – and speculating on possible reasons for these, little of this appeared to contribute to theory generation that was applied and tested in subsequent circuit challenges. While this did occur in a very small number of cases and resulted in tentative theories that were tested across simulations, general conceptual development and transfer was much more limited, and mostly 'bounded' within the challenge in

FIGURE 2
The class giving and receiving feedback on their Scratch coding.

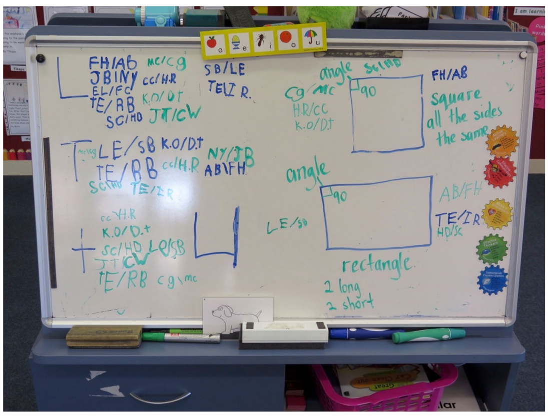

FIGURE 3
Students' procedures were checked and results recorded on the whiteboard for assessment purposes.

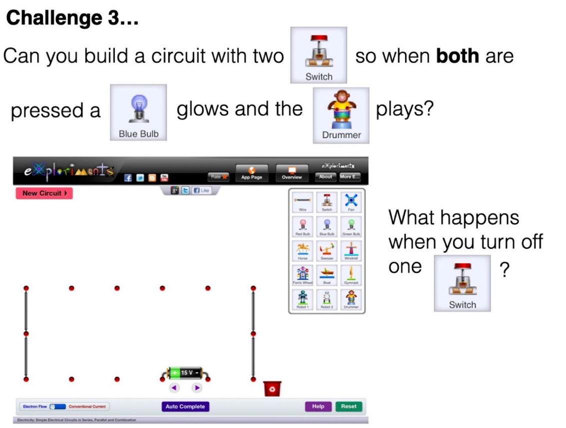

FIGURE 4
A sample 'Can You' circuit challenge.

which it was generated. However, irrespective of this finding, data strongly indicated the value of the simulations for introducing basic circuit procedural knowledge, and for general problem-solving capability development. Findings also strongly supported the efficacy of problem-based curriculum supported by guided inquiry pedagogy, as an effective and engaging learning design promoting both discipline knowledge acquisition and higher order thinking.

5.4. An exploration of online technoliteracy capability teaching and learning in early years classrooms

The final study investigated the interoperability of three different apps (Google Chrome, Apple Pages and Pic Collage or Popplet) in structured curriculum designed to introduce 6-year olds to foundational information literacy skills through authoring a simple digital information artefact. A series of lessons were planned and taught that systematically introduced the students to:

- basic web searching using keywords, strings and brief site descriptors;
- synonyms (as equivalent keywords);
- the iPad's assistive functions (e.g., text-to-speech) for helping access the meaning of information they could not read;
- copy, paste and app switcher functions;
- accessing images;
- strategies for checking the accuracy of information (e.g., by looking for similar information on two different websites);
- summarising facts from online information;
- effective design, layout and use of colour to author a simple digital information artefact.

The unit of learning was based on Matariki (the New Zealand Māori New Year) and involved students accessing and processing online information to discover 3 facts about Matariki, to be summarised and presented in a basic digital artefact authored using either Pic Collage (a poster creation app) or Popplet (a mindmapping app). The unit spanned 3 weeks with 2 lessons per week of approximately 40–45 min duration, each progressively introducing and practicing one of the skills listed previously, that were cumulatively applied to authoring the digital information artefacts. iPad display and audio recorder data were analysed using an adaptation of Durrant and Green's (2000) Literacy-Technology (or l(IT)eracy) model, for evidence of students' application of Operational competencies (technical/technology device and app skills); Knowledge-building competencies (sourcing, selecting, evaluating and processing information); and Cultural-critical competencies (understanding that information is used by people for different purposes).

Findings indicated the progressively introduced and modelled curriculum provided an effective learning structure for these students, many of whom displayed emerging to reasonably sound capabilities across each of the three Dimensions. Of particular note was students' use of device assistive features such as text-to-speech, that the teacher had modelled as a tool to help understand the meaning of information they could not read. This was used initially to determine the relevance of sites by reading the short descriptors contained on search results pages, and more extensively later on to verify information sourced from different sites. Checking the accuracy of information by locating similar material on two sites, was demonstrated by the teacher as a strategy to encourage students to verify their Matariki facts, and help them understand the importance of checking web sourced information more generally. Similarly, within the Cultural-critical dimension, this process also helped build awareness of the web as an open environment, where people are able to post information that may or may not be accurate.

The study concluded that given an appropriately structured and cumulatively designed curriculum, most of the young students were able to demonstrate at least emerging 'Technoliteracy' (Tour, 2010) capabilities across the Dimensions, when authoring their artefacts on the iPads. In practice, activities within each Dimension were interrelated, with Operational dimension competencies acting as the 'engine' driving meaning making and meaning sharing and communication, within both the Knowledge-building and Cultural-critical dimensions. There was also close interaction between the Knowledge-building and Critical-cultural dimensions, as students applied their developing information evaluation skills in discussions and decision-making related to the accuracy of the information they were accessing. Figure 5 illustrates the relationship and interaction between the Dimensions in defining these students' *Technoliteracy competencies.*

Finally, in this study it was apparent that despite their young age and being relatively new to school, most students already possessed well developed device Operational knowledge and skills that they could apply to the authoring task. This is likely due to increasingly earlier exposure to digital devices in their pre-school lives, meaning the teachers did not need to allocate substantial blocks of class time to teach basic device or app skills. This finding may be important for early years teachers' decision-making regarding the design and balance of curriculum involving the use of digital devices.

6. Discussion

The previous section briefly described methods and outcomes from four peer reviewed studies using iPads and apps for different purposes across a range of learning areas. The studies were purposively selected to provide a broad overview of device use in early years' classrooms. Their data methods also captured highly authentic information about the nature of students' learning with and through the devices, and the theoretical, pedagogical, curriculum and broader school factors that underpinned this. Maddux and Cummings (2004) earlier critique highlighted the 'fad-like' nature of technology innovations in schools. This phenomenon they attributed mainly to a lack of theoretical understanding of how and where digital innovations can best add educational value, and poor translation of research findings into teaching practices. The following addresses the research questions and responds somewhat to Maddux and Cummings critique. Due to the close relationship existing between the questions – i.e., the common features and characteristics of the classrooms and how these combined in forming effective digitally-enhanced teaching practice, to acknowledge this relationship and prevent repetition across questions, the Discussion is presented using an integrated format (Lewis et al., 2021).

Figure 6 graphically represents the relationship between four key elements that underpinned the effective, digitally-enhanced practices of teachers using mobile devices in their classrooms, as described in the four studies. Starting at the top (Figure 6:1), most influential were teachers' theoretical understandings about how learning occurs, and the type of knowledge, skills and dispositions their students needed to thrive in the future. These understandings stemmed from a commitment to professional learning-more specifically, reading and discussion of academic research and analysis of case studies of exemplary digitally-enhanced teaching, and future-oriented learning. Discussing and building knowledge from empirical research and theoretical studies aligned with the schools' commitment to maximising their investment in this area, and was a compulsory component of all teachers' professional development. Regular, dedicated professional learning sessions were held in both schools across the school year, during which teachers led discussions with colleagues about selected studies, and the implications the findings held for their practice and the future direction of school programs. This process laid the foundation for a collective understanding of the conditions under which digital technologies could make the greatest contribution to teaching and learning in the schools. The articles and subsequent discussions mainly focused on exploring contemporary learning theories and understanding the importance of curriculum that provided opportunities for collaboration, teamwork, communication, problem solving, higher order creative and critical thinking, and promoting learning independence and social skills. Consistent with findings from both Burnett et al.'s (2020) and Fokides et al.'s (2020) earlier studies, these capabilities *somewhat* aligned with

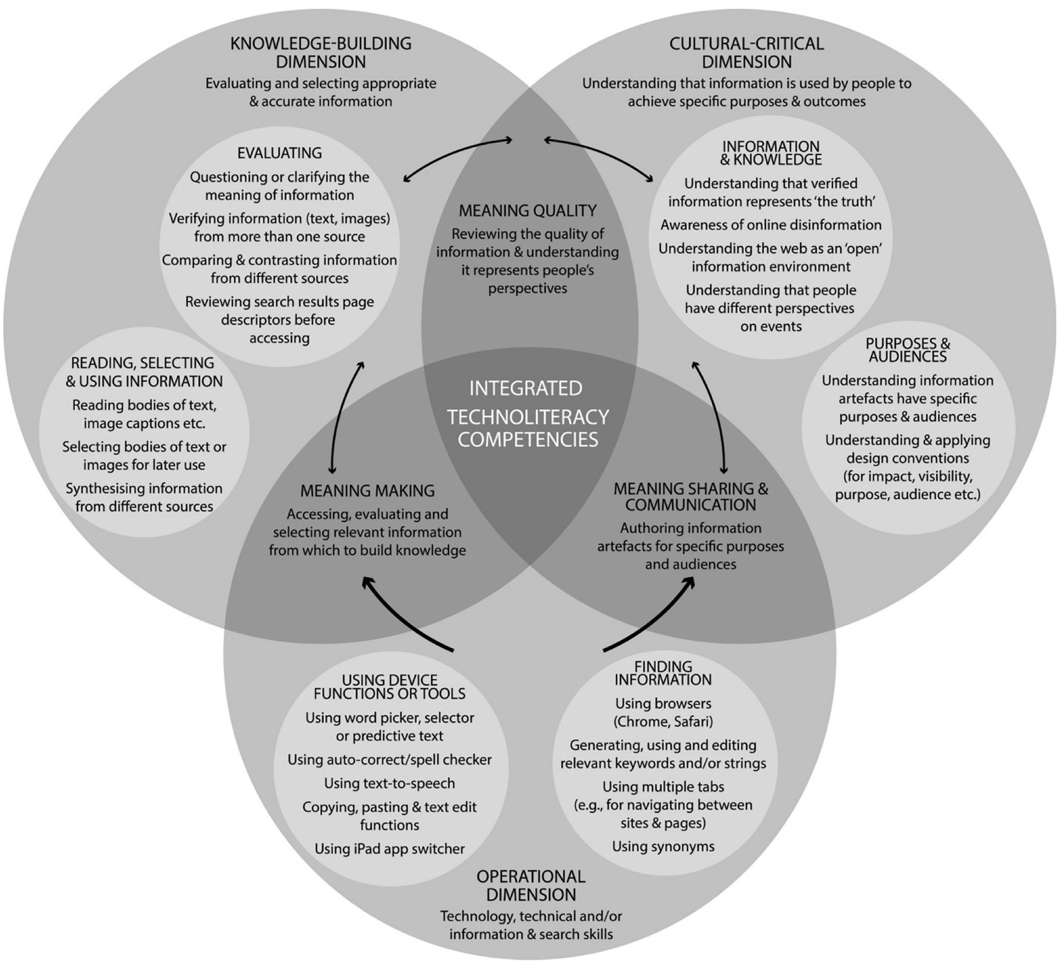

FIGURE 5
The interaction between 'Technoliteracy' dimensions (Falloon, 2023).

constructivist perspectives of knowledge building as a social and collaborative process, and were considered to be important underpinnings of effective, digitally-enhanced teaching practice.

However, while theoretical perspectives were generally constructivist-aligned, teachers' pedagogies and instructional practices were often quite pragmatic, and ranged from problem-based or guided inquiry through to direct instruction, selected on a 'fit for purpose' basis (Figure 6:2). Teachers understood the importance and relevance of their young students mastering foundational literacy and numeracy skills for maximising benefits from having access to iPads, regardless of the learning context. Similar conclusions were reached by Litster et al. (2019), who identified that young students' capacity to maximise learning benefits from any formative feedback provided by apps, was dependent on their levels of existing mathematical knowledge. Therefore, in these studies, much curriculum time was allocated to foundational literacy and numeracy instruction, some of which involved using the devices, but was mostly taught using more traditional instructional methods. When using the iPads across the curriculum, teachers leveraged as many opportunities as possible for students to use them to practice taught literacy and numeracy skills. In particular, they recognised the value of problem-based learning tasks such as those detailed previously, for providing authentic contexts for using apps to further literacy and numeracy capabilities. Teachers' theoretical understandings about learning processes and the constructivist-informed pedagogy and curriculum that resulted, provided a consistent foundation to the effective practices apparent in these studies. The availability of iPads via the schools' BYOD and mobile device pod programs, served as a supportive mechanism for operationalising teachers' theories into practice (Figure 6:4).

At a school level, principal leadership was critical for facilitating environments that supported teachers' efforts to innovate their classroom curriculum, enabling them to take full advantage of the iPads (Figure 6:3). Consistent with the earlier work of Falloon (2021), like the teachers, the principals' commitment to professional learning and understanding of learning theory was the cornerstone of their decision-making, and reflected in a sound, research-informed vision for their school and the type of environment that would deliver on that vision. This manifested in a distributed leadership style where staff were entrusted to implement digitally-enhanced learning innovations and were supported in the process, through encouragement of new ideas, risk taking, and sufficient time and resourcing. In all studies there was close alignment between principals' and teachers' visions for their schools, that created environments built on high levels of relational trust and commitment to the common objective of developing high quality, digitally-enhanced curricular.

Furthermore, all teachers in these studies held high expectations of their students, and a firm belief that with appropriate support, *all* could achieve to the highest standard across academic, personal and social measures (Figure 6:4). In this respect, curricular were designed to maximise opportunities for academic and general competency development, including building digital capabilities, higher order thinking, collaboration, and creativity. Curriculum also promoted learning independence and accountability, and fostered attitudes and dispositions such as resilience and building a growth mindset. To facilitate this, almost all work with the iPads occurred in pairs. Data from all studies strongly supported this approach, indicating substantial advantages from paired use for problem solving, oral language development, and advancing collaborative skills. Additionally, the studies revealed particular device design features that supported collaborative learning, such as the iPad display's wide viewing angle, its size, portability, multi-user touch interface, and seamless access to cloud services. Cloud-based services also supported collaboration beyond the classroom, with many teachers incorporating use of Google Classroom and similar apps in lessons and units, or

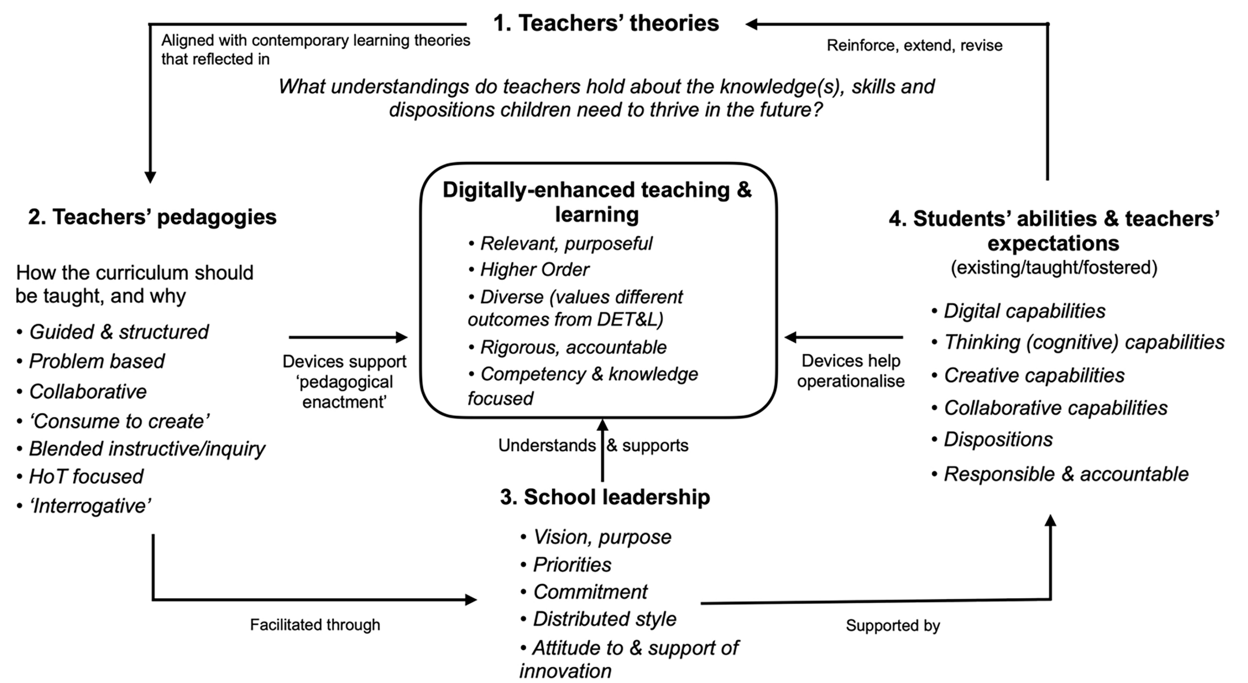

FIGURE 6
The relationship between four key elements underpinning effective mobile device use in these studies.

through students choosing to use them to collaborate on school work from home or other locations (Falloon, 2015). Their use also supported the sharing of learning progress and outcomes beyond the school, enabling feedback to be gained from relatives and external audiences that further reinforced and guided students' efforts.

7. Conclusion

The introductory review of literature highlighted poor theoretical foundations as an issue affecting the quality of much research exploring digital technology use in educational settings (e.g., Maddux, 1986; Maddux and Cummings, 2004). These authors commented that the absence of theoretical models or frameworks to help build understanding from research data, was a major concern. They claimed this contributed to educational institutions adopting digital devices "because they are there" (Maddux and Cummings, 2004, p. 523), rather than based on sound theoretical and practical knowledge of where and how they can best add educational value.

Considering commonalities existing across these four studies, it is apparent that similar theoretical understandings are needed to optimise outcomes from mobile devices in early years' classrooms. Specifically, teachers' understanding of learning theories and processes, and the type of future knowledge and capabilities needed by their students, appears central to pedagogy and curriculum that maximises benefits from having access to this technology. As illustrated in Figure 6, in these studies teachers' theories were the principal drivers of their digitally-enhanced practices, and generally aligned with social-constructivist views of learning. This manifested in curriculum designs that maximised opportunities for collaborative work and required students to engage higher order thinking to access, evaluate, synthesise, present and explain digitally-sourced information, or solve learning problems presented in simulations or open-ended, app-based tasks. The fidelity existing between theoretical understandings, pedagogy, and curriculum, was a hallmark of all teachers in these studies. This was supported by consistency in understandings between the teachers and school leadership, that established a stable and known platform and high levels of relational trust, from which various innovations could be attempted.

Historically, teacher professional learning with digital technologies has concentrated on developing technical and operational knowledge of digital devices, infrastructure and software, with the aim of supporting their 'integration' into classroom curriculum (Hansson, 2006). However, limitations to the effectiveness of this approach have been identified in studies dating back to the earliest days of so-called 'educational computing' (e.g., Ward, 2003). Analysis of commonalities across the four studies detailed in this article, instead suggests the foundation to effective practice more closely aligns with teachers' theoretical understandings about learning processes, and how this knowledge informs pedagogies and curricular incorporating digital tools. They signal that more time should be invested in teacher professional learning that interrogates theoretical perspectives that appear influential in forming effective, digitally-enhanced teaching practice. Unlike device or software-specific programs, professional development focused on core theoretical understandings may provide teachers with a more transferable knowledgebase, against which the potential of new innovations can be evaluated, and decisions made about if and how they can enhance classroom learning. If we are to address Maddux's enduring "pendulum syndrome" (1984, p. 27) where innovation in education can be said to "lurch from one fad to the next" (Masters, 2002, p. 1), it seems more fundamental, theory-based understandings are needed about where and how mobile devices can add value in our classrooms, and the conditions under which this can be established and sustained.

Data availability statement

The datasets presented in this article are not readily available because due to the sensitive nature of data collected during this study, including video and audio recordings of young children that disclose personal and identifying information, ethical clearance was not granted for open data access. Requests to access the datasets should be directed to g.falloon@federation.edu.au.

Ethics statement

The studies involving human participants were reviewed and approved by The University of Waikato Education Research Ethics Committee. All Figures displaying students' faces have been approved for publication by respective parents and/or caregivers.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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