TEACHING & LEARNING
RESEARCH INITIATIVE
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Experiences and reflections of teachers on the use of mixed reality technologies to foster cross-curricular learning opportunities

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March 2022

1. Introduction

This study aimed to explore how the purposeful integration of new technology, specifically mixed reality (MR), can support learning across the curriculum through the development of digital artefacts. The study focused on exploring the experiences of teachers at two high schools who were supported by digital technologies teachers and the lead researcher to use digital technologies with students to create MR artefacts in different subject areas.

Recent changes to the Technology learning areas of *The New Zealand Curriculum* drove the motivation for this research project. The changes to the curriculum were designed to support students to develop the digital literacies vital to engage in an increasingly digital society (Ministry of Education, 2017). The need to attract more students into digital technologies was also a driver for these changes and it resulted in the strengthening of the digital technologies | hangarau matihiko (DT|HM) curriculum content with two areas being added to the Technology strand of the curriculum: computational thinking (DTCT), and designing and developing digital outcomes (DDDO).

Reorienting the use of technology away from consumption to creation has meant students need to be supported to become active creators of digital artefacts. The changes have been designed to be wide-reaching and have emphasised that digital technologies, as a subject, needs to be integrated from the first year of schooling, and the design and development of digital artifacts need to be conceptualised in authentic contexts across the curriculum (Ministry of Education, 2017).

Despite these aspirations, schools are still grappling with how to effectively integrate this new focus (Education Review Office, 2019). To explore how schools could leverage new technology to meet the aims of the new DT|HM areas, a pilot action research study was undertaken to explore how two schools have approached these changes and to integrate DT|HM across the curriculum. The primary research question driving the project was:

> How can digital technologies, specifically mixed reality (MR) tools, be adopted to facilitate learning across the curriculum?

This study explored the experiences and reflections of teachers integrating MR to address this question. To answer the research question in detail, we identified four sub-research questions:

a) How can teachers be stimulated to enhance learners' co-constructive activities and support cross-curricular activities?

b) How can learners be involved in, and take responsibility for, the construction of their own learning artefacts (as opposed to just using pre-given learning artefacts)?

c) What are the barriers and enablers for the integration of MR to support a range of learning outcomes across subjects?

d) How effectively can this approach be adopted in other schools?

1.1 Why mixed reality (MR)?

Within MR, there is a continuum between virtual and augmented reality. Where, on one side, students are embedded within a virtual environment (virtual reality—VR), and, on the other, the digital experience is overlaid on a real-world experience (augmented reality—AR). MR embraces the spectrum between the real and the virtual; the balance of these may vary depending on the application. When compared with other technologies, MR has specific affordances that make it a promising tool for learners (Bacca et al., 2014; MacCallum & Jamieson, 2017). Using MR has proven to be a powerful tool to support learning and develop

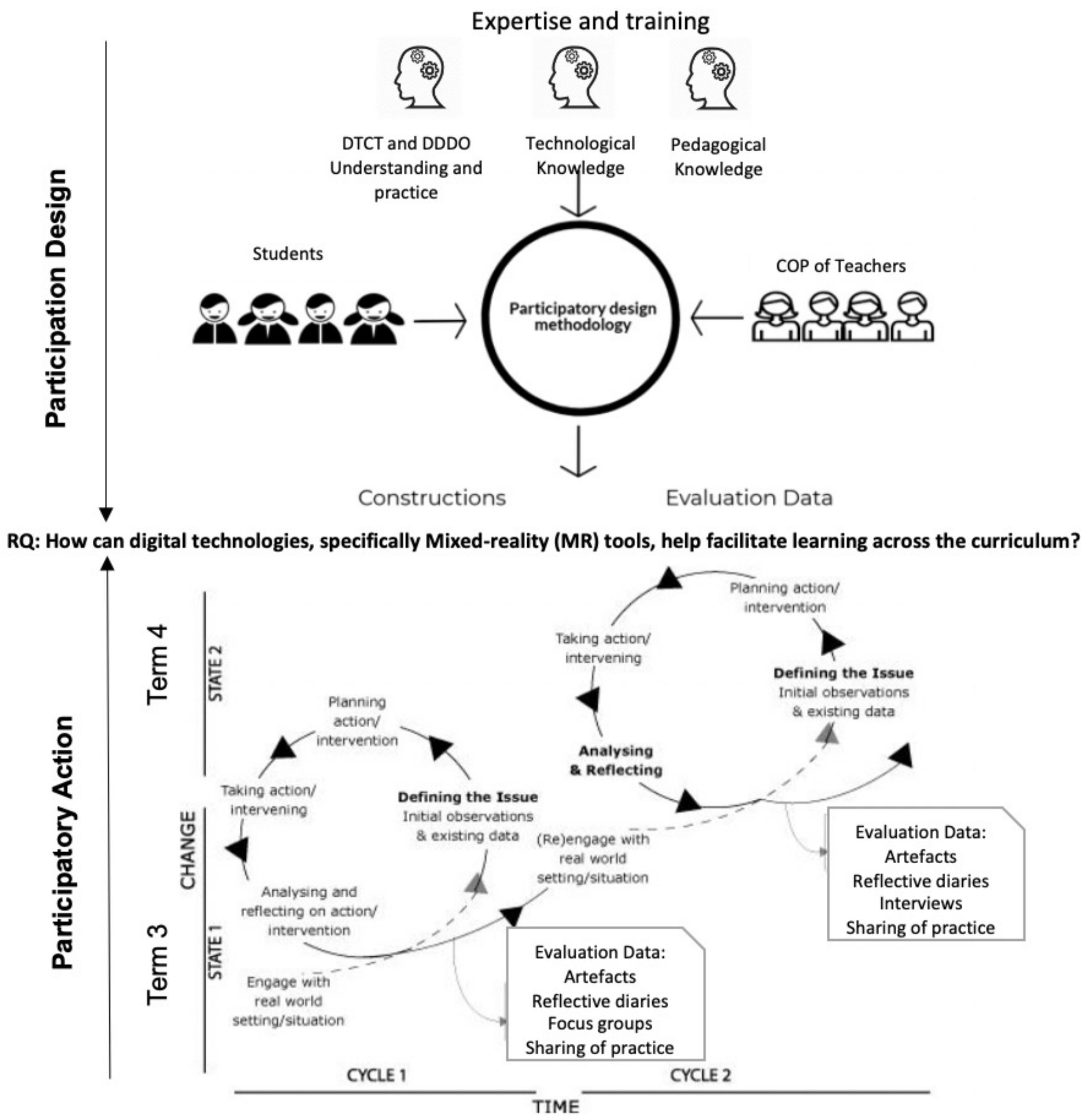
21st century learning capabilities (Bower et al., 2014; Schrier, 2006). Since MR (and specifically AR) allows for the embedding of digital, location-specific information into a physical site, enabling learning to be contextual, it provides new opportunities for learners to develop and curate their own experiences (Schrier, 2006).

The development of MR artefacts can support students to conceptualise and develop their learning while also supporting the development of broader concepts of computational thinking (CT). CT has focused on "solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science" (Wing, 2006, p. 33). While CT is accepted as something that can be developed in computer science, it can also be developed across the curriculum (Fluck et al., 2016). This integration has the potential to transform what is taught in other subject areas and supports deeper engagement with learning across the curriculum (Fluck, 2003). The study therefore focused on how student-created MR artefacts could support learning across the curriculum by leveraging the unique qualities MR provides for learning.

2. Research design

This pilot study adopted a participatory action research design, a cyclic process of research, reflection, and action (MacDonald, 2012). This approach enabled the teachers to design and research their practice and collaborate with other teachers across subject disciplines in their schools. Teachers were given autonomy on how they integrated the technology into their classrooms, so their own needs and contexts drove the approaches and objectives for its integration. Figure 1 provides an overview of this approach, which will be discussed in more detail in the next section.

FIGURE 1: **The participatory action research design**



2.1 The participatory action research (PAR) cycles

The study drew on two action cycles of interaction and reflection. These cycles of action involved a series of workshops provided by the researcher and supported by the digital technologies teachers at each school. The focus of these workshops was to provide the teachers with a foundational knowledge of the MR technologies that they could use in their classrooms. The teachers were introduced to tools and technologies that could be used to create MR experiences. A Communities of Practice (CoP) approach was adopted to support their sharing and learning.

To keep the approach simple, the tools used to create MR experiences were kept to a minimum. The main software tool used was CoSpaces (https://cospaces.io/edu/), a browser-based service that can be used by students to create both AR and VR experiences. Merge Cubes were used with CoSpaces to create interactive AR experiences. With these tools, students could create increasingly sophisticated artefacts that integrated both block and script-based coding. ActionBound (https://en.actionbound.com/) was used to create AR experiences (and was specifically used to create the scavenger hunts as it supported geolocation).

The teachers were also provided with hardware to use in their classes—mobile devices, 360-degree cameras, VR mobile headsets, and Merge Cubes. In addition, teachers had the autonomy to explore other MR tools, such as Minecraft.

The adoption of two action cycles supported teachers to develop and build on their approaches within each cycle. The original plan was that the initial training would happen in the first term of 2020, then the classroom integration would happen in the second term, with a reconceptualisation of this integration in the third term. However, due to COVID-19, the use of these tools in the schools was delayed to the third term of 2020, when the teachers were back in the classroom. This delay, however, meant that the teachers had a longer period to learn and explore with the tools, so they were more prepared to integrate these tools into the classroom by term three.

At the end of each action cycle, the teachers' approaches and perceptions were gathered and analysed. This included the collection and analysis of the following data:

- Reflective diaries: Reflections were documented by the teachers as they progressed through the project (both iterations). These were used to shape the interview questions that were used in the final interview with the teachers.
- Focus groups: At the end of the first cycle a focus group was undertaken in the form of a brainstorming workshop. The participants shared their different approaches with the group and then in groups explored what the barriers, the enablers, and potential opportunities were, based on their current experiences. This approach helped to support the PAR approach, where sharing of experiences helped to shape a shared perspective of the project and influence the next cycle of integration.
- Interviews: At the end of the project, interviews were undertaken and focused on addressing overarching perceptions concerning the integration of MR within their classrooms. These interviews were thematically coded to map to the research questions.
- Artefacts: Students' work and teachers' lessons were also collected to understand the approaches taken by teachers to integrate DT into their classes and were used to better understand how MR was used within each subject.

2.2 The participants and their focus

The two schools involved in this project provided a good counterpoint to compare integration and approaches. Both schools cater for Years 9–13 students but had diverse populations of students. Tables 1 and 2 summarise the teachers involved in each school.

TABLE 1: **Teachers involved from school 1 (high proportion of Māori students)**

Pseudonym	Confidence with DT	Teaching area(s)
Maree	Medium	English and Digital technologies
Tania	High	Digital technologies (head of department)
Matua	Low	Performing arts (Māori)
Cara	Medium	Mathematics, English, Social studies, Health, and PE (homeroom teacher)
Mary	Low	Mathematics, English, Social studies, Health, and PE (homeroom teacher)
Silvia	Medium	Science, Mathematics
Sarah	Low	Science, Mathematics

TABLE 2: **Teachers involved from school 2 (an all-girls school)**

Pseudonym	Confidence with DT	Teaching area(s)
Sarah	Low	Science
Fiona	Low	Science
Matt	Medium	Mathematics
Gina	Low	Mathematics
Peter	High	Digital technologies
Steve	Medium–high	Languages (and eLearning support)
Tim	Medium–high	Geography (and eLearning support)

Both schools include large populations that are underrepresented within science, technology, engineering, and mathematics (STEM) domains (Mpofu, 2019). The inclusion of these schools provided a good opportunity to examine how the use of digital technologies to teach science, technology, engineering, the arts, and mathematics (STEAM) subjects may excite, support, and generate interest in digital technologies.

Despite having an opportunity to focus on any year or subject, all participant teachers elected to focus on their Years 9 and 10 classes (students aged between 12 and 15 years). The decision to focus on junior classes meant that the research could be undertaken without needing to engage with National Certificate of Educational Achievement (NCEA) external assessment, which was seen as a barrier to integration.

3. Findings

The findings of this study are now presented in response to the broad question of how digital technologies, specifically mixed reality (MR) tools, can be adopted to facilitate learning across the curriculum. Each of the four sub-questions is examined in turn.

3.1 How can teachers be stimulated to enhance learners' co-constructive activities and support cross-curricular activities?

The project highlighted that, for teachers to enhance learners' co-constructive activities and support cross-curricular activities, they need to be actively supported to develop appropriate ways to integrate DT into their specific subject areas. By focusing on supporting teachers to explore DT and identify appropriate knowledge intersections, we can help them to provide students with opportunities to apply their DT knowledge through co-constructed cross-curricular activities. While training and support will be instrumental in facilitating this exploration, the establishment of CoPs provides ongoing support. These CoPs help support teachers to make clear links across subject areas where teachers collaborated with each other to explore how subjects could be integrated through the development of digital artefacts.

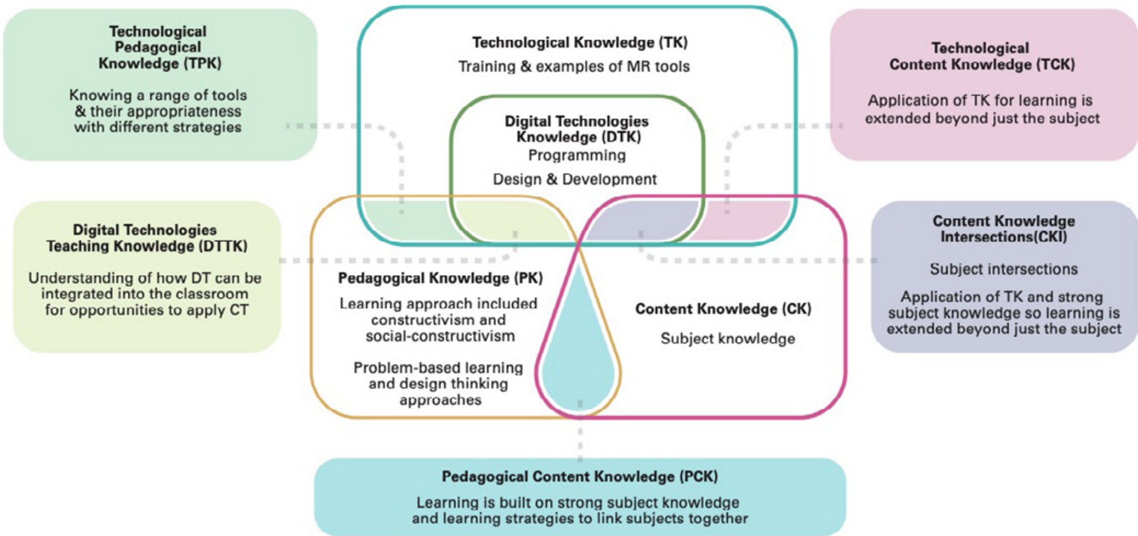
3.1.1 Focus on building deeper knowledge about how DT can intersect across the curriculum

We found that supporting teachers to build their technical, pedagogical, and content knowledge (TPACK) stimulated them to enhance learners' co-constructive activities. This approach, however, required teachers to develop a more nuanced technological knowledge. The study identified that an additional knowledge point—digital technologies knowledge (DTK)—was needed in order for teachers to design learning that enabled the development of digital artefacts (Figure 2). The project established that new intersections between pedagogical content knowledge (PCK) and DTK were needed that would enable teachers to support students to create digital artefacts. Therefore, teachers need to develop the following additional knowledge areas:

Digital technologies teaching knowledge (DTTK): Understanding of how different pedagogical knowledge (PK) and approaches, especially student-led approaches, could be adopted alongside DT skills for artefact development into the different subjects.

Content knowledge intersections (CKI): Exploration of the links between DT and content knowledge (CK) and specific subject learning outcomes to understand how these can be integrated.

FIGURE 2: **Extending the TPACK framework with DTTK and subsequent CKI**



Addressing these intersections requires a wide set of skills and knowledge (Margot & Kettler, 2019). Teachers need to be able to effectively weave together subjects, which often requires them to draw on new approaches and technologies to support this learning.

> I liked the thought of sitting [DT] within Māori Performing Arts … [Its integration provided] a more authentic integration of the technology to take learning out of the digital technology classroom and put it in other areas other subject areas … The project helped our team to uncover how enthusiastic our ākonga are to embrace the opportunities that these technologies offer. Students have been incredibly engaged in the process and have found ways in which to use AR and VR to help them understand concepts that would have otherwise been less accessible. Students have been able to build experiences for each other to enrich their learning also; this reinforces a strong sense of mahi tahi, or sharing learning. (Maree)

3.1.2 Set up Communities of Practice where teachers can reinforce and build practice

The opportunity to participate in a digital technology focused CoP provided teachers with the support they required to enhance learners' co-constructive activities and support cross-curricular activities. The CoPs were used to reinforce and build the technological and pedagogical knowledge they gained from the training workshops. Regular online and offline group sessions were set up to provide teachers with opportunities to share approaches and learn together. Connecting the teachers across the two schools enabled the participants to draw on each other's ideas and gain wider support. As highlighted by one teacher:

> I've just really enjoyed seeing what other schools are doing with the same technology. It was nice to reach out to each other, such different schools as well. It's just great to see how we both approached the challenge. (Maree)

Participating in CoPs meant the teachers were supported beyond the initial training sessions.

> There were many different facets to the implementation of MR in a kura, so it is important to share the load. Where possible, we shared ideas and enjoyed co-teaching in each other's classes, using our own strengths to explore the technology and situating the technology more fully within each subject. (Tania)

Those working together on common projects met regularly to plan and discuss approaches. In one school, these meetings were more formal, scheduled each week to discuss the plan. They used Google Classroom to share resources along with a Google Document which included their lesson plans. They also updated this document regularly with their group reflections of how each session went. For the other school, planning and meetings happened in a more ad hoc way and reflected the more organic nature of their collaboration where teachers supported each other when needed.

3.1.3 Support non-DT teachers to work alongside the DT teachers

Having a DT teacher working alongside non-DT teachers enabled non-DT teachers to lead the integration of technology in their classrooms. In each school, the DT teachers were involved in the CoP where they supported the other teachers with integrating the technology and developing digital artefacts. In addition, for one school, the eLearning team also provided support around the pedagogical aspects of integration of technology in the classroom. While it was expected that the DT teachers would teach the DT curriculum alongside the other teachers, it transpired that, in all but one project, the non-DT teachers led the integration of technology and the DT teachers played a more supportive role. This supporting approach was appreciated by the staff as they could focus more on their own subjects and knew they had support if needed around the DT.

> It was really great that I knew that Peter [DT teacher] had my back when it came to the digital skills, all the coding and those kinds of things. [It meant] I didn't have to concentrate on or look up, or see how I am supposed to be teaching this. I know how they learnt some of this before but I'm not a DT teacher. So, it was really great that he could help them with that as well. (Gina)

This approach meant that students could apply their existing DT knowledge in more authentic subject-driven contexts.

3.2. How can learners be involved in, and take responsibility for, the construction of their own learning artefacts (as opposed to just using pre-given learning artefacts)?

In the project, the teachers used different approaches to integrating technology into their subjects, focusing on applying constructionist approaches. While many used problem-based learning (PBL) approaches as a way to drive learning, there were also examples where technology was used in a more directed way.

3.2.1 Use PBL to support the integration of DT

PBL is a student-centred pedagogy in which students learn about a subject through the experience of solving an open-ended problem. PBL emphasises the integration of knowledge and skills and has been shown to support deeper learning when integrated across the curriculum rather than being used in a single course (Dolmans et al., 2016).

In both schools, PBL was used to tie subject areas together where students needed to apply their knowledge across subjects to solve a problem. In both schools, the solution was focused on developing a digital solution. Design thinking approaches were used to help support the process of examining the issue and designing the solution.

In the first school, DT was integrated into an existing STEM programme which involved a group of teachers (two science, two mathematics) working across subjects to engage students in a student-led problem-based learning initiative focused on solving problems around recycling/sustainable practices. The premise behind including MR was that it would provide students with the option of either designing a solution or communicating the solution or problem through MR. This approach meant students were exposed to a range of MR experiences, leading to MR being used in their solution in different ways including AR quizzes to collect feedback on their solution, AR simulations to provide interactive information about their solutions, and interactive VR experiences that demonstrated their ideas (for example, one group created a virtual plastic-free shop to help showcase the benefits of going plastic free).

In the second school, the DT subject was integrated into the Māori performing arts (MPA) class. Students in both classes worked together to explore issues around the school topic of "change". The students decided to explore how they could better support students transitioning from intermediate to high school. They then came up with ways that drew in both subjects. Solutions included creating virtual and augmented tours of the school, which blended information about the school alongside cultural knowledge, therefore drawing on both the DT and MPA skills.

The opportunity for learning in both approaches was particularly powerful to extend students' learning. As related by one of the teachers involved:

> [The students] weren't just the end-user of the technology they were using it for educational purposes to present their ideas to get other students to look at their [artefacts] and then to also use them. [Students were not just] exploring something someone else had made, but they had to make their own and had to figure out how to do it, and what steps to go through, and it was trial and error … students need to persevere and learn debugging skills, and even just the logic of the connecting things together and applying their learning … there's a lot more self-thinking, collaborative learning, less learning for a test and forgetting it afterwards and working with real broad problems. (Sarah)

3.2.2 Adopt different approaches to integrate DT

Using DT within (rather than across) subjects enabled students to deepen subject-specific knowledge. In addition to the examples above, the teachers also integrated DT into their classes in a number of other ways:

- Using Minecraft with a Japanese class. The approach focused on students creating virtual Japanese villages to show their understanding of cultural practices and provide a virtual experience to improve their language skills.
- Augmented reality simulations of the solar system to showcase science and mathematics learning to design and animate the simulations.
- Augmented reality mathematics trails and scavenger hunts around the school where students developed and shared their own location-based quizzes.
- Interactive MR artefacts developed by students to demonstrate understanding of a range of topics including statistics, nutritional information, and te reo Māori.

These activities provided students with opportunities to create digital artefacts and link with CT concepts around computational and algorithmic processes. The application of DT provided students with creative approaches for applying their learning. As highlighted by one teacher, who got her students to create the AR solar systems, this approach enabled the students to:

… test their knowledge or research further, both to create it correctly and how to code it, in order to create what they want to create. It's not just Science [content] it has also brought in the digital aspect as well, at the same time, without them ever really thinking about it they're doing both together. So they're actually learning both … The process of creation enabled them to apply their knowledge making sure that they actually understood what they had learnt but in a way that is applied and creative. They're doing something they want to do. (Gina)

By integrating DT in this manner, teachers enabled their students to be more involved in, and take responsibility for, the construction of their own learning artefacts (as opposed to using existing artefacts). The integration of DT in this manner enabled the teachers to draw on the concepts of constructionism, providing new ways for contextualising diverse subject knowledge.

3.3 What are the enablers and barriers for the integration of MR to support a range of learning outcomes across subjects?

In the study, we identified that integrating MR provided new opportunities for integrating diverse learning outcomes. We also found that the integration of MR raises barriers that will need to be overcome if wider adoption is to occur. The following section highlights the enablers and barriers that were identified in the project.

3.3.1 Enablers to integration

The use of MR provided new opportunities for learners to creatively demonstrate and contextualise their learning in more authentic contexts. Learning became student-led and enabled students to showcase their learning in new ways.

There is that ability for them to have real student choice, not like, 'This is what you're doing and that's it.' There's no variation [creating artefacts meant] they have ownership of it, and they've created something themselves. [We had] students who worked on the project in their own time, students who never did anything extra before. You've got students who might have avoided trying to do work who have gone and had a go. (Silvia)

Is a totally different way of thinking than [students] getting out their workbooks. Doing a practical lesson where you're [creating something]. It's a different way of thinking, but it's great because it appeals to different students and they're learning new skills. (Gina)

The integration of MR provided opportunities for wider connections across subjects, but also provided new opportunities to connect these subjects to real-world applications and make learning more holistic.

… problem-based learning is more holistic, there is so much sort of unacknowledged learning that happens, and that you're actually getting to work through with them. That might be very unique from one team to another, but it opens up those contexts that you can have those conversations around, but if you just stuck to the curriculum that you wouldn't necessarily be exploring. Once again it's exposure and giving students an opportunity to apply their learning. (Gina)

The approach enabled students to shine in different ways.

… some of the best ideas came out of some of those students that generally struggled in my class. If I think of [the group that explored] fencing of the farm, and the effort that they put into that and their little activities that they incorporated with the technology, they did a great job. It was a really good effort, especially for a group of young women who are mathematically challenged and challenged in terms of focus and motivation; however, they came up with a project idea and ran with it … with the use of the technology they had to rise to the challenge of using it, but within the group, they appointed a person who had a bit of a flair for it … and through the use of technology I think it gave an extra dimension to what potentially could have been not as exciting or an interesting project. (Gina)

Often students needed to work together and help each other.

> There were some, of course, that had different strengths in the group, and they'd help the others. That was a great thing about the teamwork. They'd each lean on each other if they needed to, and they'd lead at other times. And so, that was pretty cool, and they could also ask other groups in the classroom. (Fiona)

The teacher became the facilitator of the learning, and, where the students had more knowledge, they took a stronger lead. For example, one teacher recounted that:

> [when] they are explaining what they are doing with the technology and I say to them, 'I don't know what you're talking about'. Then we're saying 'You gotta do it like this Matua'. And they love it, showing us how it works, and joke, 'You're supposed to be the teacher' but really they enjoyed it. I sort of trick them into extending themselves by saying 'I don't know, can you show me?' They then front up and they owned the learning … it's a different skill of being able to teach the technology. That's what they demonstrate and are getting better at, and not just using [technology] … it's part of the learning. (Matua)

From this, key affordances of MR were identified, showing how it can support a range of learning outcomes across subjects (Table 3). Adopting an affordance lens provides a level of abstraction that goes beyond the specific context of adoption. Affordances are relatively generalisable and constant across specific implementations so are not tied to a particular approach. As emphasised by one teacher involved in the study:

> It's important to try to work out what lends itself to what you're trying to do and not just having it as an extra—'a just because'. Making it an important part of the learning is important … this will make the use beyond the gimmick and rather provide a solid learning component. (Sarah)

Table 3 captures the affordances of MR that act as enablers for integration.

TABLE 3: **The key affordances of MR for integrating learning outcomes across subjects**

Affordance	Description	An example of where this was integrated
Visualisation of the 3D and the invisible	3D digital representations of objects enable students to visualise and explore abstract concepts or unobservable phenomena in depth. MR can make the invisible visible to extend learning.	Student-created simulated solar system. Students were given the autonomy to apply their learning about planets (such as order, sizing, and facts) and apply coding skills to make them interactive.
Social and shared engagement	MR can support engagement and interaction between students co-located or remotely. In many MR experiences, the co-exploration of experiences enables learning to be more authentic and engaging.	The development of scavenger hunts, maths trails, and apps used in the different contexts (including science, languages, maths) drew on a social process in their development. Students supported each other in the development of artefacts, then shared the outputs to learn from each other.
Portability of the device to interact with a location or bring students into an environment	Both AR and VR can provide opportunities for unique experiences that would otherwise be impossible. The use of VR to bring a student into a location or AR for students to engage within a location provides for different aspects of situated cognition.	Virtual field trips (VFT) were used to prepare students for a real field trip and provided initial learning. Students then created their own VFT to demonstrate their learning and share it with others.
		The AR scavenger hunt supported ubiquitous, collaborative, and situated learning opportunities while on the field trip.
Making learning explicit	The construction of MR artefacts enables students to demonstrate their understanding and make learning more visible.	Collaborative development of a virtual Japanese village to practise developed students' language skills and understanding of Japanese culture.

Supporting student-led learning and leadership	Students were enabled to drive their own learning and choose how they approached technology and development. They were also able to take ownership in their learning and many students took a leadership role in supporting others with integrating the technology.	As a group, students created AR and VR products developed to teach others about their STEM project solutions. The development was focused on understanding their users' needs.

3.3.2 Barriers to integration

Alongside the enablers that supported the integration of MR there were also several barriers identified that will need to be overcome to ensure that this approach is successful and more widely adopted.

3.3.2.1 Support for and valuing the integration of DT framed within PCK is needed

Supporting teachers to integrate technology requires the integration of PCK alongside stronger technical skills (DTK). The adoption of appropriate pedagogical approaches (DTTK) which enables the creation of artefacts to sit alongside their subject (CKI) is needed. Teachers need to be supported in their development of these competencies. Not all teachers are fully equipped to support learners to develop their own artefacts or see how digital technologies can be effectively integrated across subjects. However, providing teachers with an opportunity to explore new tools and approaches, integrating digital technologies and related concepts into their subjects, will mean teachers can better conceptualise the use of digital technologies to engage learning across different learning areas. Training is needed to expose teachers to the affordances of MR and enable them to develop their DTK and DTTK skills. Providing time and space for teachers to play and explore alongside others and share their approaches and learning was a key driver for successful integration and helped teachers build their understanding of the intersections between subjects (CKI).

In addition to time and space for exploration, teachers need to be able to work with both their DT and non-DT peers. The project highlighted the need for schools to move beyond just covering DT outcomes in isolated contexts. While teaching DT fundamentals does not need to happen in each subject, students need the opportunity to use these skills across different learning areas in authentic and contextualised ways. This can only happen when DT is integrated and valued throughout the school and where every teacher has some fundamental understanding of DTK and their intersections with CK and PK.

3.3.2.2 Students require support and scaffolding

The integration of technology enables students to engage with their learning in new and creative ways; however, students need to be able to exercise this creativity and challenge themselves to engage with the technology more deeply. This was highlighted by one of the teachers in the project, who explained that she often had to push her students to extend their learning and application of DT. She noted that students were used to being given technology to use or led through the process of development. However, she felt that more student-led approaches were required to extend their learning. In her class, when students were creating a simulated solar system she noted that:

> The less able students were probably just going to copy, and the more capable were [able to pick up the technology and were] away and could do the whole lot. The [less confident students were happy to follow the example] but then I was trying to challenge them saying, 'No you've got to actually develop this, it's not enough just to do that, you've got to get this moving and think about the movement and which way it should turn…', some of them got the planets orbiting the wrong way whereas some of them went further by adding more detail and additional planets. (Silvia)

The integration of student-led approaches and constructionist practices requires students to be more active agents in their learning; however, this requires significant scaffolding for students to apply these approaches.

> [DT integration] requires student agency. You need to scaffold this too, and those things that you slowly integrate, and starting low. (Silvia)

> They love the quick gratification but when it comes down to the hard graft sometimes it took a little bit more of stepping them through it, making them stop and then taking time to really go through it slowly so that they did understand what was required … They seem to rush things at times, and they don't necessarily put the time and thought in. They just think, 'Oh yeah it's done'. 'Well no it's not done. You've just done something very basic then you're actually quite capable of creating something really creative.' (Gina)

3.3.2.3 Technical support and resources are essential

Alongside providing students and teachers with skills and knowledge to integrate DT, additional support is needed. This includes the provision of resources, but also support around making them available and usable within lessons. In addition to lesson plans, rubrics, and technical manuals, resources also include the supply of technology and providing time relief for teachers to plan and work together.

For teachers who were comfortable with the technology, having some support in the class (such as from the eLearning team or other teachers) helped to get them comfortable with the tools.

> Having good technical support was vital, also having extra people in the room made such a difference in terms of the feel at the end of the lesson and getting the feedback from the students seeing how they felt, and it was very clear that the students who, within the class, there were one or two groups who are very technologically savvy, and there were others that were a mixture of students who could be easily distracted. And so, having someone who could just swing past every so often and keeping tabs on some of these other groups so that they were keeping on task, keeping them motivated, and make them realise what they could do with this technology. (Gina)

3.3.2.4 Driving school culture to innovate and integrate new approaches

Adopting new practices for integrating MR moves teachers out of their comfort zones and requires them not only to see value in the process but also to prioritise this approach. As one participant noted, achieving buy-in requires structural and cultural changes within the school:

> [Ongoing adoption] means buy-in from the Senior Leadership Team to say that this is a viable way of learning. Teachers also need to see the value [in how the integration of digital artefacts] can connect two different subjects to increase that motivation and engagement and effective learning. [Support from leadership is needed to provide] space for exploration time in the timetable to allow for [collaboration between teachers and subject]. (Tania)

For the approach to be successful, it requires leadership to prioritise and drive cultural change. School innovation requires a whole-school approach that is supported, prioritised, and driven by those at the top (Hammond, 2020). Repositioning the engagement of digital technologies requires schools to not only provide the technical and structural infrastructure but also additional support for the development of CoPs, providing training and time for exploration, and supporting the adoption of technology. This includes providing access to professional development, access to tools, and training. Encouraging wider teacher buy-in will mean a wider cultural change and eliminate these fundamental barriers.

3.3.2.5 Buy-in of new teaching practices and approaches

To facilitate the integration, teachers reported that they needed time to learn and explore new approaches for the integration of DT. Providing teachers with an opportunity to explore new tools and approaches meant the teachers could better understand how the integration of DT could be framed within their subjects and therefore support buy-in.

Supporting problem-solving and real-world learning approaches meant the adoption of student-led instruction where students were able to drive their own learning.

> [The way the technology was drawn into the class allowed students to go] into different directions, and required them to take ownership and learn what they didn't know … It supposed learning agency … and differentiating that learning process. (Tania)

To facilitate these new approaches the teachers needed to draw on new ways to structure their teaching. Drawing on new approaches (such as design thinking) enabled students to adopt creative, interdisciplinary processes and encouraged students to consider different perspectives and approaches in how they conceptualised and solved problems. As highlighted by Tania, the approach:

> … enabled problem-solving approaches to be integrated into the class. It was really good to see how students might approach the problem-solving process, and work through this … It was interesting to see how they interacted.

3.3.2.6 Structural/policy changes are needed to support innovation

To support these approaches, policies and structural barriers need to be removed to support teachers. The study identified a range of issues that need to be resolved at a school level that impeded their ability to integrate DT effectively and collaborate with other teachers. These included barriers around the structuring of the timetable, which meant that classes could not be easily combined or resulted in set periods that were too short for students to fully engage with the activities. Teachers also required autonomy over their classes and content. It was identified that rigid structures and siloing of subjects meant that crossing of subject boundaries requires significant co-ordination and flexibility to work around this rigidity.

> [Integration is hampered when teachers are in the mindset that] 'You're encroaching in our subject area and we still want those hours, and we don't want to give up an hour a week for this', because they didn't see the benefits. And so we're still at that stagnant stage where full school integration is limited and we can't tap into the digital technologies as well as we would like. [Because the timetable isn't aligned we are not] offering technologies at the same time [as the other subjects]. This has made it very difficult to integrate … it's got to come from the top I think for it to work, and it's got to be sold by them as well. (Fiona)

> [Flexibility is needed for] time in class … more time was needed to allow for this type of learning … as I had students in a homeroom (where subjects were grouped) this meant there was flexibility around how I integrated subjects. I had time to sort out issues and students had more time to engage and push their learning. (Silvia)

Setting up policies that facilitated and encouraged cross-teaching and collaboration enabled innovation. Supporting teachers to work together and support each other is vital.

> I would think that if teachers had the opportunity to work together too, the ones that are less confident … it can be daunting if you're not a technology person but you're wanting to give this a go then it is a lot easier if you can work as a group … So maybe that's the way to start to get everybody on board with it. Because that is what worked for me, just thinking I could work in a group. That was less daunting and then I was able to go off on my own and think, 'No I can do this. It's fine. It's not that bad. It's not that hard, I just need to learn how to do it.' And you don't know what you don't know. (Mary)

Alongside these internal school barriers, the teachers also acknowledged the challenges associated with external assessments. One teacher commented:

> I talk to a lot of teachers, especially around the integration of STEM, and they say, 'No, it can't possibly work at NCEA level because it's all the units and stuff.' [Wider adoption] requires a cultural shift. It's a culture where it's not just you as the teacher, but it's the whole ecosystem of everyone buying into it and making it work … [Teachers have to] step back and take a holistic view and not just focus on their subjects … [being] worried about their own units, it's not going to ever work. (Fiona)

> I think it becomes more challenging because we have a little bit more flexibility with the juniors in terms of timing and what we can cover … whereas it becomes more prescribed as you get to NCEA and we're like, 'No we just have to do this', and it's linked quite strongly to actual assessment that we're doing … Senior classes, especially Years 12 and 13, you have to just get through all this stuff and you're constantly pushing the girls—sorry, we can't slow down, we haven't got time for that, moving on to the next bit, and just teaching this content. Hardly even time to add related experiences, it's all so pushed and it is a real shame. (Gina)

In summary, while offering huge potential, fundamental issues still impact the rollout of approaches like the one explored in this research project. While participating teachers were positive and able to integrate MR in the ways they wanted, there were many external barriers that they had less control over that inhibited their adoption and that needed to be managed from an institutional level. The next section explores how these enablers and inhibitors can be framed to support wider adoption.

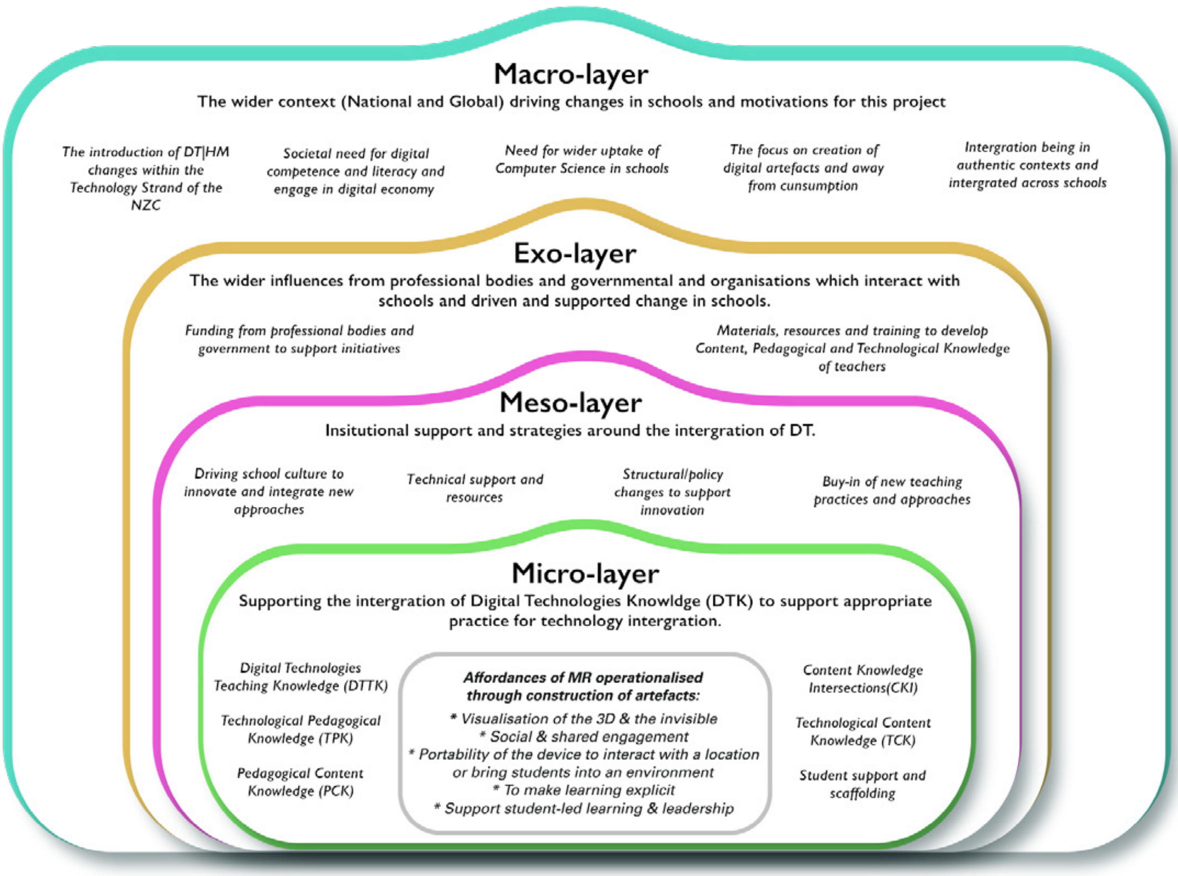
3.4 How effectively can this approach be adopted in other schools?

Supporting the integration of DT in schools requires a deeper understanding of the impact this approach will have at a systems level. By exploring these issues through the different layers of the ecological model (macro, exo, meso, and micro) we can develop a wider perspective of the factors that influence the adoption of MR within the schools. The integration of technology by teachers is not independent of the complex school ecosystem in which teachers engage. Therefore, for other schools to adopt this approach, schools need to balance the needs, effects, and influences the approaches and integration of any teacher-driven initiative have.

Drawing on Bronfenbrenner's (1993) ecological approach, a framework was developed to contextualise and frame the issues identified in this project that need to be considered when adopting this approach in other schools (Figure 3). The model highlights that effective and ongoing integration of technology is driven by broad ecological influences that play a fundamental role in how technology is integrated. These influences go beyond the classroom and therefore wider consideration is needed when exploring the adoption of technology. As explored in Toh (2016), "the school organisation, including its nested sub-systems and the broader socio-cultural environment it interacts with, can shape and create a constellation of conditions over time to either impede or promulgate the use of ICT for pedagogical-related innovations" (p. 146). While classroom practice may drive initial adoption and integration, we need to also consider how the supporting ecology will influence and drive the sustained adoption of technology.

It is therefore by drawing on this ecological view that we can identify how other schools can adopt a similar approach. The next section draws on the implications framed in these macro, exo, meso, and micro forces.

FIGURE 3: **Ecological framework for the integration of digital technology across the curriculum**



4. Implications for practice, policy, and research

Looking forward, this framework provides the basis for future research to further explore how we can more effectively support schools with this shift in practice. This research has provided the following implications for practice, policy, and research.

4.1 Implications for practice

- The development of digital artefacts, to support the development of digital skills and cross-curriculum learning, does not have to be confined to the digital technologies classroom. The construction of digital artefacts not only enables students to demonstrate and apply their learning across subjects but also supports the development of digital skills.
- Teachers require additional support to develop a deeper understanding of the new areas of the Technology strand in *The New Zealand Curriculum* and how this reshapes how technology works across the curriculum. This includes development of new knowledge but also providing support for integration.
- Enabling teachers to develop communities of practice and collaborate across subjects is essential for long-term innovation and integration. Showcasing examples and providing resources will also be vital to support wider uptake.

4.2 Implications for policy

- To support wider adoption and integration of digital technologies across the curriculum, more support is needed. Teachers require the autonomy to explore and apply technology within their classes which requires time, access, training, and pedagogical and technical support.
- Ongoing adoption requires a change in the structure of schools, along with a culture change that makes these approaches a priority. Teachers need to be actively supported by school management and senior leadership in helping them to better engage with digital technologies.

4.3 Implications for research

- MR provides for new approaches for application across the curriculum; however, wider research is needed to explore how these approaches can be integrated to support further, ongoing adoption.
- Teachers have a positive perception towards drawing digital technologies into and across the curriculum; however, further research is needed to explore how to support wider application and assess the impact on students.
- The ecological framework outlines factors at the micro, meso, exo, and macro layers that can support teachers and students to take full advantage of these opportunities in digital teaching and learning; however, these factors need further exploration and application in different contexts.

5. Conclusion

The focus of this research was to explore how digital technologies, specifically mixed reality (MR) tools, can be adopted to facilitate learning across the curriculum. In this study, we identified that the purposeful integration of digital technologies provided new opportunities for innovative, inclusive learning that would otherwise be difficult or impossible to support. Identifying the affordances of MR provided new learning opportunities and provided for a richer and diverse set of learning outcomes. The designing and development of digital artefacts enabled learning across subjects and enriched the learning experience, drawing on a wider range of 21st century competencies. The study concluded with a framework that identified the specific factors that need to be considered by other schools embarking on similar initiatives.

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