Wilf Malcolm Institute
of Educational Research
Te Pūtahi Rangahau Mātauranga o Wilf Malcolm
THE UNIVERSITY OF WAIKATO

A socio-technological assemblage when teaching with mobile technology apps

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Editor: Kerry Earl Rinehart

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Abstract

In this paper we consider how the integration of mobile technology apps into classroom practice can form an alternative pedagogical medium that influences the learning process in mathematics. We give an account of one aspect of a research project that examined the use of tablets and apps in primary-school mathematics programmes and report teacher and student perceptions on how they used the apps, in combination with other manipulatives, to solve problems. Through teacher and researcher co-inquiry, three themes emerged: multi-modal affordances, collaboration, and assemblages. We examined how the interplay between these themes evoked ranges of social, tangible, and digital entities resulting in different learning experiences. We draw on notions of collectives to articulate a socio-technological assemblage and suggest that the notion of an assemblage helps to understand how teachers can use educational technologies to support new learning experiences in their mathematics classrooms.

Keywords

Collectives; classroom practice; collaborative learning; elementary mathematics education; mobile technologies

Introduction

Mobile technologies (MTs) populate our social and occupational landscapes. Their presence is ubiquitous, including in educative settings, while their low instrumentation and ease of operation, coupled with the interaction being focused primarily on touch and visual elements, make using them intuitive for learners. The ever-evolving nature of MTs and their increasing presence has created a challenge for teachers of mathematics to integrate them into existing practices or use them in innovative, effective ways. This challenge has been accentuated recently through the closure of schools and other

educational institutes during the Covid-19 pandemic, and the consequential use of apps as learning pivoted from face-to-face to online learning (Allen, et al., 2020; Engelbrecht, et al., 2020). Synonymous with MTs in educative settings is the use of educational apps. These vary in quality regarding their mathematical and pedagogical approach, evoking questions regarding the appropriateness of some apps (e.g., Philip & Garcia, 2014). In addition, concern has been raised that if the shift to educational technologies, including the use of MTs, is rushed, for instance through the changes imposed by Covid-19, then there is a risk of teachers returning to transmission pedagogies (Bakker & Wagner, 2020). But if MTs are a relatively enduring element in mathematics classrooms, their potential to enhance mathematical learning requires examination. We need to consider that if teachers use MT apps in their mathematics programmes, how do learners engage with them in their mathematics learning, and how might they influence mathematical understanding. This is of high interest to the education community as we grapple with what works most effectively with learning through education technologies more broadly, and how to transition the multitude of teachers who use transmission modes of teaching to more student-centred approaches.

Previous research has suggested that MTs have the potential for offering fresh approaches to engage with mathematical concepts and processes, and for re-envisaging aspects of mathematical education (e.g., Attard, et al., 2020; Borba & Villareal, 2005; Calder, 2011, Calder & Murphy, 2018a). In this paper, we explore this potential by examining student and teacher views on the use of apps, and consider how the affordances of these apps inter-relate with other entities, including social, material, and digital. We present data from a larger study on the use of tablets, in two primary school settings. The aim of the project was to engage in a co-inquiry with teachers into the ways that tablets and apps might enhance student learning in mathematics. Through discussion with the teachers, a question arose in relation to the use of a screen-casting app to record calculation strategies and how the affordances of the app might have presented an alternative learning experience to the use of pen and paper. It was suggested that, to examine the learning experience provided by the apps, we needed to look further at the inter-relationships between the learner, the digital medium and other entities—the social, technical, and material—involved in a learning experience. Hence, the research question examined in this paper was: How might inter-relationships between social and technical entities, coupled with other manipulatives, form an alternative pedagogical medium that influences the learning process?

Affordances

Affordances were perceived as the inter-relationships between the learner and the environment (Gibson, 1977). Drawing on Gibson, Greeno (1994) theorised that an affordance inter-connects the attributes of an object in the environment (e.g., a tool) with an interactive activity undertaken by an agent (e.g., a user). The agent engages with the activity depending on the tool's attributes and the user's ability. Each affordance exists only in relation to the user's ability, and vice-versa (Greeno 1994), with the two linked in an ongoing iterative system (Chemero, 2003). In terms of mathematics education, Brown (2005) identified affordances as the inter-connectivity between the user and the artefact. The notion of affordances also acknowledges how the digital medium exerts influence on the students' approach, whilst the students' existing knowledge guides the use of the technology. They are mutually influential (Calder & Murphy, 2018a). However, there are some areas of caution too with the detrimental effect on calculation skills identified (Gardiner, 2001) and the use of multimedia in eLearning being distracting to students and affecting their concentration, for example, during the Covid-19 pandemic (Al-Yasiri et al., 2021).

One affordance frequently associated with digital environments is the aspect of multiple representations. The ability to link and explore visual, symbolic, and numerical representations simultaneously in a dynamic way has been recognised extensively in research (e.g., Sharples et al., 2007;

Calder, 2011). In addition, concrete manipulatives play a key role in learning when used with discrimination to best facilitate understanding (Resnick & Omanson, 1987). Linking material and virtual manipulatives can enhance children's mathematical processes and understanding (Suh & Moyer, 2007; Terry, 1995; Zacharia & Constantinou, 2008). For instance, Takahashi (2002) reported that students' understanding profited from using both physical and virtual geoboards.

Research has further shown that the affordances of interactivity and instantaneous feedback in digital environments foster experimentation allowing space for students to explore and take risks when using manipulatives (Calder & Campbell, 2016). For example, with the use of MTs, the screen-casting app that we questioned earlier allows students to write or draw on a digital white board screen, manipulate digital representations, and then audio/video record the screen to create an individual or group presentation of their mathematical processes and solutions. As such, the app offers both a haptic affordance mediated through the glass interface by touch (rather than through a mouse or keyboard) (Sinclair & Heyd-Metzuyanim, 2014) and an aural representation that students can listen to. Screen-casting illustrates how the various representations used in problem solving (e.g., concrete, visual, symbolic, haptic, and aural affordances) are simultaneously linked together. Simultaneous linking focuses students' attention on the mathematical objects (focused constraint) and encourages creativity and variety in students' solutions (creative variation) (Moyer-Packenham & Westenskow, 2013). In addition, such apps allow students to model their processes in a dynamic, reflective way with other learners, evoking social mediation alongside simultaneous interaction with the digital media, representations, symbols, and mathematical ideas. This social, technical interaction influences the learning experience (e.g., Calder, 2011).

Social perspective

The use of digital technology in education has been viewed as social for some time (e.g., Wegerif & Dawes, 2004; Bernacki, et al., 2020). In particular, the ubiquitous features of MT devices enable the coordination of collaborative activities as students move with the device and work with other students at different locations (Zurita & Nussbaum, 2004). Studies have shown that young primary school students often pass MTs from one to another or rotate the device for the other to view more easily and to interact with the content (e.g., Falloon & Khoo, 2014), hence acting as a tool for learning in private spaces as well as in public collaborative spaces (Fisher et al., 2013).

Furthermore, the joint coordination of a task, alongside the use of personal MT, enables students to communicate and negotiate to support decision-making (Zurita & Nussbaum, 2004). They become involved in "a coordinated joint commitment to a shared goal" where collaboration goes beyond the sharing of ideas and task coordination to renegotiation of meaning (Mercer & Littleton, 2007, p. 23). As collaboration moves towards the renegotiation of ideas, the MT acts as a mode of reasoning in sharing and establishing common knowledge. The MT is seen as a tool, not just to bring ideas to life, but to open spaces where teachers and learners engage with the manipulation of visual worlds as they collaborate and talk with each other, thus enabling learners to play and think together and to foster creative thinking and capacity for learning (Wegerif, 2007). Such use is notable where app design facilitates open experimentation and stimulus for discussion (Calder, 2011), and not just consumption where students respond to onscreen prompts (Falloon & Khoo, 2014) or practise rote-learning formula and procedures (Olive et al., 2010). In such open tasks, the visual affordances and non-judgemental nature of feedback encourage the setting of informal conjectures that encourage further collaboration (Calder, 2011).

We suggest that the interaction inherent in blending digital and material media draws on and evokes social elements. A theoretical perspective that acknowledges the inter-relationship of the multi-modal representations of the tablet with the learner, along with the mathematics, concrete manipulatives, and

social interaction with others, could help to draw these entities together and understand how the use of tablets might influence the learning experience in primary mathematics classrooms. The learning experience and the associated learning will be determined to some extent by this integrated weave of digital and material elements and the attending social components (Calder & Murphy, 2018b). How virtual and physical manipulatives interact, while simultaneously evoking associated social elements, suggest that they form a mutually influential assemblage, and we explore these notions next.

Collectives and the notion of assemblage

In this section, we relate Delanda's (2006) notion of assemblage with other theoretical perspectives suggestive of collectives. Delanda's assemblage theory explored how the properties of the whole emerge from the interaction of the parts, and that complexity (social, organic, or technical) is a compound of a variety of wholes, each emerging from the interaction of their parts. In this way, a whole does not consist of a range of discrete entities but as a synthesis of the properties of entities and is not reducible to its parts.

Within studies of digital technology in mathematics, Borba and Villarreal (2005) proposed a notion of collectives to explain the inter-relationship between the social and the technical where different software enabled different mathematics (e.g., dynamic geometry) within a collective of humans and media. A further collective notion for learning with MT is suggested by Meyer (2015). She suggested the integration of MTs within a wide ecology of learning resources in a way that distributes knowledge across learners within multifarious interconnected systems. She used the term "socio-material bricolage" to describe the "ecological entanglement of material and social aspects of teaching and learning with technology" (Meyer, 2015, p. 28), suggesting a tapestry of tools influential in students' dialogue, learning experience, and mathematical thinking in personalised ways.

These two collective perspectives indicate the situated contribution of MTs to learning and the transformation of learning spaces. Borba and Villareal consider the social-technical elements and Meyer the notion of bricolage in students finding their own relationships between MTs and other resources. MT is another tool used in the classroom alongside other resources.

In considering the dilemma introduced at the beginning of this article, the use of the screen casting app suggested not just a tool within a collective or bricolage to assist learning but an assemblage that transformed the learning. Hence, we propose that Delanda's (2006) notion of assemblage has the potential to take the situated contribution of MTs into a more complex realm of social, technical, and material. The dynamic, haptic, and aural affordances of the MTs suggest an assemblage of virtual manipulatives, verbal and symbolic recordings, and haptic experiences. These, along with concrete manipulatives and collaboration, suggest a new context for learning.

From both Delanda (2006) and Borba and Villarreal's (2005) perspectives, the whole (in this case the learning experience) becomes an assemblage, thus constituting the articulation of discursive and non-discursive elements of objects and actions. However, a key distinction in Delanda's proposal is that all entities and relationships, whether social or non-social, are ontologically and epistemologically indistinct. As such, a learning experience is no longer a means of representing knowledge but one of understanding through reflection, interaction, and creation of new knowledge. Borba and Villareal's perspective saw understanding emerging from the reconciliation of re-engagements of the collectives of learners, media, and environmental aspects with the mathematical phenomena. Borba and Villarreal propose an iterative process as each engagement reorganised the mathematical thinking and initiated a fresh perspective that, in turn, transforms the nature of each subsequent interaction with the task. The learners then re-engage with the task from this new perspective until some form of new shared negotiated understanding occurs (Calder, 2011). In some respects, this notion resonates with de Freitas and Sinclair's (2014) identification of finger-screen-voice-five assemblages through which a child was

involved in a rhythmic engagement when counting to five with the Touch Counts app, and to Ng and Sinclair's (2015) use of touchscreen dynamic geometry. In both studies, assemblages were conceived as being fluent rather than static and that they emerge in varying constitutions and permutations.

We draw on these different perspectives to help understand the merging of learners with MTs within a situated learning experience. Delanda's (2006) and Borba and Villareal's (2005) theories suggest some form of new shared understanding and knowledge. Delanda proposed that social assemblages may be codified through language, whereas non-social or technical may not. However, Borba and Villareal's iterative process suggested that the very use of the technical can be seen as expression and this is illustrated through the multi-representational and multi-modal affordances of the MT selected by the user to express and create knowledge (Murphy & Calder, 2017). Coupled with their hand actions with the touch interface of the tablet screen, learners frame a way of expressing and creating knowledge. Hence, the digital media influences the engagement and ensuing dialogue in particular ways, which, with self-reflection or further dialogue with others, transforms the learners' perspective (Borba & Villarreal, 2005; Calder, 2011).

In this paper, we propose the notion of an assemblage of digital, concrete, and social elements which we term a socio-technological assemblage (STA) and consider how this notion of assemblage can further help understand how MT apps can support students in creating new knowledge. We report on teachers and students' perceptions and refer to video recordings of the use of several mathematics apps, at times coupled with materials, while solving mathematical problems. We use these findings to illustrate and explain STA and to investigate how STA can help to understand the influence of the tablet, as an example of MT, on learning experiences.

Methodology

The research for the larger two-year project used an interpretive methodology related to the building of knowledge and aligned with teacher and researcher co-inquiry whereby the university researchers and practising teachers work as co-inquirers and co-learners (Hennessy, 2014). We report on data from the first year of the project with three teachers experienced with using MT in their mathematics programmes. The aim of the study was to gain insights into participants' practice rather than determine generalisations pertaining to the population (Etikan et al., 2016). Hence, a purposive sample was utilised to examine the practices of teachers already using apps in their classroom programmes. One teacher taught a Year 4 class (7- and 8-year-olds) in a school that used a Bring Your Own Device (BYOD) approach using a variety of tablets, while the other two teachers team-taught in a combined Year 5 and 6 class (9- to 11-year-olds) in a school with one-to-one provision of iPads (80 students in total). We use the term tablets to refer to the variety of MTs that students in this study engaged with in their mathematics classrooms. In both classrooms, the use of tablets was fully integrated into the teachers' mathematics programmes. All lessons involved use of the devices with whole class, group, and individual settings. Hence, the data presented here relate to the normal activities of each of the classrooms.

Qualitative data were obtained through different sources: individual teacher interviews, student focus group interviews, student blogs and video recordings of classroom observations. Two individual interviews, with each of the three teachers purposefully selected for the project, and two focused group interviews, with six students from each class, were carried out, once at the beginning and once at the end of the first year. The students were selected by the teachers to provide a range of abilities, gender, and age, and the group remained consistent across the two interviews. Semi-structured interview schedules were developed for teachers to determine their perspectives and rationale for using apps with their students, and for student interviews to determine their views regarding the use of apps in meeting their mathematical needs (Kvale, 1996). The student blogs were obtained, from students willing to

participate, halfway through the first year of the project to gain in-the-moment student views on the use of apps. Prompts were given to support students in writing their blogs. During classroom observations, video recordings were gathered from teacher-led use of apps, independent student group work, and individual work on three occasions by the researchers. The researchers also used these opportunities to ask students to explain their thinking as they solved mathematics problems. The project was given ethical approval through the university's ethics committee and all participants gave their informed consent.

Co-inquiry (Bray et al., 2000) was managed through a cycle of research meetings, involving teachers and researchers, via a mainly inductive or grounded method, with a focus on one emerging theme for each of the three iterations of classroom observations in Phases 1 and 2 (see Table 1). While the researchers carried out initial sampling of the data and identified initial themes and codes, each of the themes was refined through joint critical reflection between the teachers and researchers in the meetings. Data were then analysed further using NVivo according to the refined themes, and a final review of themes was carried out jointly after the fourth iteration of classroom observations and in Phase 3. This grounded approach explored the use of apps through the eyes of the participants to explain the complexities of the phenomenon (Hutchinson, 2005).

Table 1.   *Phases of Research Showing Cycle of Iteration for Emerging Themes*

Phase 1: Preparation and identification of initial theme	
Research meeting 1	Discuss aims of the project
Data collection 1	Teacher and student interviews First iteration of classroom observation
Research meeting 2	Co-inquiry review of data to identify initial emerging theme
Data collection 2	Second iteration of classroom observation
Data analysis	Coding of data using NVivo against emerging theme
Phase 2: Reflection and identification of further themes	
Research meeting 3	Co-inquiry review of data to refine theme and identify a further emerging theme
Data collection 3	Third iteration of classroom observation
Research meeting 4	Co-inquiry review of data to refine themes and identify a third emerging theme
Data collection 4	Fourth iteration of classroom observation
Research meeting 5	Co-inquiry review of data and themes
Data analysis	Coding of data using NVivo against refined themes
Phase 3: Development of the framework	
Research meeting 6	Develop framework based on the three identified themes
Data collection	Teacher and student interviews
Data analysis	Complete cross-analysis of data using NVivo

Note: Ethical approval for the research was granted through the University of Waikato, Division of Education Research Ethics committee, FEDU017/20, with informed consent given by all participants.

Results and analysis

Emerging themes

The three themes that emerged and were refined through the co-inquiry process were multi-modal affordances, collaboration, and assemblages. These emerged according to a triangulation of the data from interviews, blogs, and classroom observation video recordings. Each data set, including video recordings, were coded within NVivo, and the cross-analysis of data carried out in Phase 3 indicated alignment across all data sets. We present examples from the different data sets that illustrate the three themes. The first theme that emerged related to the features of the tablets and multimodal representations that we term multi-modal affordances.

Multi-modal affordances

Viewpoints from student blogs and interviews referred to dynamic multi-modal representations, hand actions, risk-taking, and exploration, suggesting visual, haptic, and aural affordances. Students also referred to mediation through programming and the use of different pedagogical media.

For example, features of the Multiplier app illustrated both visual and haptic affordances as the students used their fingers to draw out the array and had both visual (including colour coding) and numeric representations simultaneously linked together (Figure 1). The student group used the affordances of the iPad and app to solve the problem, suggesting a multi-levelled problem-solving environment. For instance, students noted: "Multiplier helps me because it shows what it looks like, so I know how to do it. You tap on which one you think is correct" (Y5/6 student blogs).
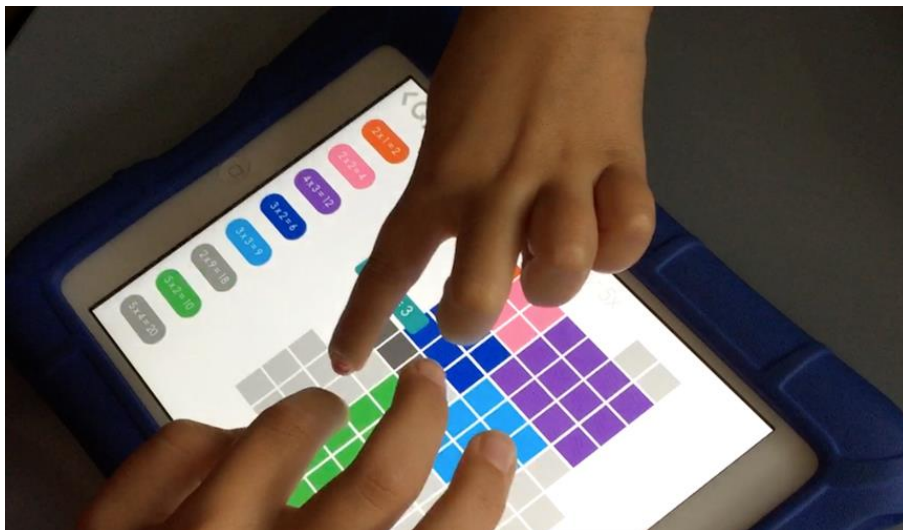
Figure 1.   Students using the visual, haptic, and interactive affordances (Y5/6 observational data).

The use of a programming app (Tickle) with Sphero robots made strong physical and visual connections too, especially in geometry. "Tickle helped me program robots to draw triangles." And: "We used this app [Tickle] to learn about making shapes, angles, and vertices" (Y5/6 student blogs).

Students also referred to the multimodal affordances of screen-casting, using the Explain Everything app.

You can record your learning and you can see what stage you are working on and: Instead of writing in our book we can just record our voices and upload it to Google classroom!

It helped to solve my problems—by using Explain Everything you can record and pause and think about what you're saying. (Y5/6 student blogs)

Students again referred to drawing on the tablet screens or tapping to select a tool, indicating the haptic affordance of the tablet. Several students indicated that the opportunity to record their voices whilst writing and drawing, seemed important. "… hard to explain without writing down. You can write it down as well as explaining it while you're recording" (Y5/6 student interview).

The opportunity to pause and edit recordings also appeared to be significant in supporting students in expressing their thinking. "The cool thing is that you can actually pause it and then think about what you're going to do" (Y5/6 student interview).

The Math Shake app generates mathematics problems at various levels and gives access to a range of mathematical representations (e.g., ten frames and empty number lines) and the use of a screen-casting function (Figure 2). Students commented how the different representations introduced them to new strategies using the representations. "I like learning new strategies, using a number line and place value." And: "I learnt how to use the reversing strategy on the number line" (Y5/6 student interview).
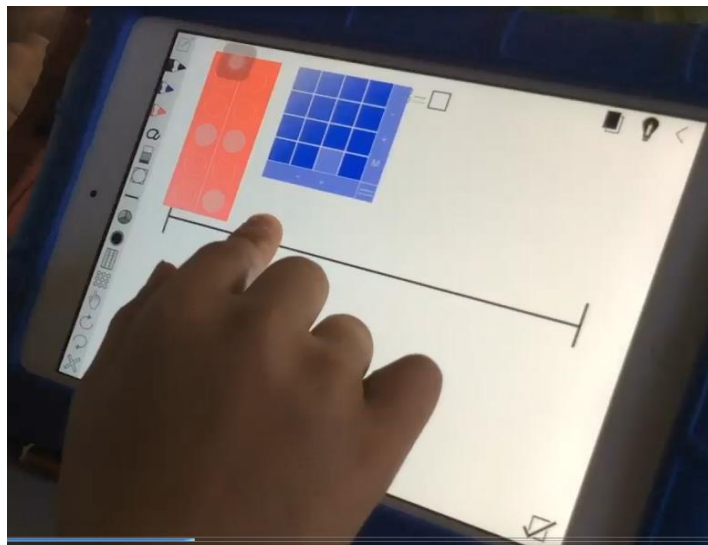

Figure 2.   Student using different representations on the Math Shake app (Y5/6 observational data).

The different data sets indicated that the learning opportunities from multi-modal affordances extended beyond individual work and was indicative of collaboration. "You can share docs with someone—so you can tap on the same thing, so you get ideas quicker" (Y5/6 student interview).

This last point suggests the second theme that emerged in the research meetings: collaboration.

Collaboration

Students indicated how much they liked to collaborate through sharing, helping, and giving ideas, as ways to help each other's learning. This sharing sometimes happened through incidental, spontaneous situations. "Luke asks me to work with him because we like to help each other out and solve things—so if we don't get something we try and work it out" (Y4 student blog).

Teacher interviews also indicated incidental and spontaneous collaboration, and one teacher related this to the flexible learning environment. "I was surprised at how much collaboration went on because they were allowed to sit anywhere they wanted … they would just ask their neighbour something and then there was this little conversation" (Jane, Y4 teacher interview).

Such statements were supported by video data of classroom observations. Students often showed the tablet screens to each other.

Teachers also made deliberate decisions to group students to share common tasks. One teacher explained her intention was that students "can see how others do it differently and can learn from each other" (Trish, Y5 teacher interview). The classroom observation video data also showed students working together in pairs or small groups. On some occasions, students shared work on the one tablet, whereas on other occasions, students worked on their own devices to compare solutions and strategies. Several of these classroom observations showed students using the Explain Everything screen-casting app to collaborate on a strategy (Figure 3).

Figure 3.   Two students collaborate to create a screencast that explains equal addition (Y5/6 Classroom Observation).

Other classroom observations indicated that students did not always reach a consensus on the strategies to use when solving a calculation; for example, the use of equal addition in a subtraction problem, and students used screen-casting to discuss different strategies. Alan (Y6 teacher) explained how he deliberately set collaborative tasks to encourage negotiation as students debated the merits of each other's strategies before deciding on the most efficient strategy.

> That's another thing we did—we sent them off in groups to work on a strategy. They each used a different strategy, video recorded their thinking, came back together, argued about which strategy was the best by watching the videos and then deciding. (Alan, Y6 teacher interview)

The data indicated that the tablets enabled incidental opportunities for collaborative approaches to learning as well as directed use for coordinated tasks, often using shared devices to create one document or screen cast. In both instances, the use of apps provided help and support through explanations and modelling but also initiated discussion, with the potential to renegotiate thinking. This in turn initiated further engagement with the tablet. The opportunity for students to collaborate and engage with the tablet suggested the third emerging theme in relation to the notion of an assemblage. This notion was

particularly exemplified as students employed features of the tablets and the apps alongside other concrete materials within social interactions, hence the emergence of the next theme: assemblage.

Assemblages

The data were cohesive regarding the connection between the use of the apps, concrete materials, and the social interaction evoked through engaging with the mathematical activities. For instance, one teacher observed students using the tablet to investigate a problem in context, then using counters and rods, all the time interacting with each other and the range of tools. Students used features of the app and a white table for story boarding the screencast of their strategy and solution. The screencast included video footage and audio explanation of their strategy and solution. The apps evoked a collaborative approach while they also afforded the recording of their thinking and solution.

Students related to a mixed use of pedagogical media. For example, the students were comfortable moving between their tablet and more traditional media, including exercise books and white tables. This was observed in the classroom (Figure 4). "I can still switch back to my book easy and it's still easy to use apps" (Y5/6 student blog).

Figure 4.   Students solving a number problem in pairs using a mixture of writing and digital activity (Y5/6 Classroom Observation).

The teachers also identified an assemblage of material, digital, and social elements in the data related to their perceptions of the learning experience.

> I had some children doing measurement and so they filmed each other and talked about it and filmed the different lengths and you know, the heights of children and the big, bigger, and biggest and all that sort of thing … they got to put that into an iMovie and make it about their maths. (Trish, Y5 teacher interview)

At times, the teachers indicated that students used the digital resources to stimulate thinking, while simultaneously evoking an assemblage of different media.

> They used the iPad to watch a video and they did a brainstorm on a piece of paper about what a triangle is and different types of triangles, what internal angles are and external angles and things like that and then we … the kids used that information to create some triangles. (Trish, Y5 teacher interview)

Here, we see the use of different technologies (including paper) in an interconnected way with social elements, such as brainstorming, which became the key part of the assemblage.

The classroom observation data also showed how students used concrete manipulatives to make sense of and solve the problem. They then photographed or videoed their process to include in their screencast presentation to portray their mathematical thinking and solution (Figure 5).

Figure 5.   Student photographing their concrete manipulative process for their presentation (Y5/6 Classroom Observation).

These data demonstrated a blending of concrete and digital pedagogical media, but there were also social elements evident in the discussion and negotiation of what would be included and how they would undertake the process, as well as their aural explanation. Other observational data (see Figure 6) illustrated the use of a range of media to explore and illustrate situations related to a problem engaged with by a group as they made a group recording that involved area and volume. The different representations, with the students transitioning between them, also required some negotiation of shared understandings.

Figure 6.   Students using a range of media to explore area and volume (Y5/6 Classroom Observation).

One teacher, Alan, referred to these connections as an ecosystem:

> There's a really big app ecosystem—I don't think there's many other devices that you can program on the iPad and then program robots and record your voice and make videos and all that stuff. It's a very rich ecosystem. (Alan, Y6 teacher interview)

Another teacher, Trish, explained how apps involving screen-casting were powerful agents in learning as the students were, creating something … explaining their own thinking, creating their own content, their own language. Students also referred to the use of screen casting as a physical object and talked of videoing themselves doing maths and recording their working. As one said: "It's just like making a movie for maths" (Y5/6 student blog).

Observational data also indicated that the students, at times, used a variety of digital phenomena within an assemblage. They might use two or three different apps with different representations to assist with their interpretation and understanding of a problem. At times, they discussed these representations as they negotiated shared understandings or possible solutions to problems, but on other occasions the discussion was enabling the students to transition between different representations; for instance, one in a draw app and one in Minecraft. In Figure 7 students are exploring a volume problem, including creating a model of the situation in Minecraft. Both were used in the creation of a screen cast that was used to demonstrate their thinking and solution.

Figure 7.   Student data illustrating an assemblage as they engage with volume models related to the Minecraft activity (Y5/6 Classroom Observation).

This example of a classroom observation showed students' negotiation of ideas in relation to volume. The classroom observation video of this group of three indicated how the students contested ideas and processes as they negotiated how to use Minecraft to set up the box dimensions. Again, the negotiation furthered the engagement with the app.

Aaron	Okay, five lots of five blocks.
Zac	Yep, five blocks.
Don	Shall we use a line? [He indicated where the five blocks might go on the screen]

Zac	No, not five blocks up!
Aaron	Yes, you need to use it there.
Don	Yeah, there.
Zac	Is it? No, this one. [Pointed to the screen]
Aaron	You need the five blocks across and going up. [Indicated on the screen]
Zac	Oh yeah, yeah now I see.
	(Y5/6 classroom observation)

The data illustrated contestation of ideas that led to a shared understanding of the task and of volume. The affordances of the apps offered different representations of the situation, while the interaction in the dialogue enabled the movement between and within representations that helped facilitate clarification and understanding (Zac's understanding of volume in particular). There was a unique interplay of social and technical elements within the negotiation of meaning that illustrates an assemblage of social, digital, and material elements. However, the social elements were more than dialogue and collaboration. The students' preconceptions changed with each interpretation of the situation. These preconceptions were influential elements of an assemblage of social and technical entities.

Discussion

The first two emerging themes, multi-modal affordances and collaboration are discussed briefly regarding their relationship with the assemblage theme and with our notion of STA. This is an overall tenet of our study in exploring our research question: How might an assemblage of social and technical entities, coupled with other manipulatives, form an alternative pedagogical medium that might influence the learning process?

With regard to the multi-modal affordance theme, student and teacher responses in the interviews and blogs acknowledged the potential of the tablet in manipulating objects dynamically onscreen. They spoke of acting directly with the object and referred to tapping or drawing on the screen. The screen-casting feature was seen to introduce multiple modes and representations as students worked simultaneously with dynamic visual recordings (drawing and manipulating digital and writing symbols and words), along with speech and physical materials, to create a dynamic aural-visual representation. The coding app Tickle was used to connect numeric and symbolic representations in the coding with the physical movements of the Sphero and the creation of geometric shapes. Although the movements were mediated by the coding process, the students commented on the connections between the movements and their learning.

With regard to the collaboration theme, the sharing of tablets often involved students pointing directly to features on the screen, suggesting a nascent deictic form of collaboration, where students were drawing attention to an object or image spatially, and hence helping to share their thinking with another student. This nascent form has been reported with young students with non-digital materials (e.g., Murphy, 2014); however, the ubiquitous nature of the tablets appeared to aid opportunities for sharing and pointing. Students also engaged with tablets deliberately to share their use of strategies to negotiate their thinking, suggesting that social interaction could move beyond sharing and pointing to develop a joint, negotiated understanding. Examples from classroom observations indicated how negotiation and decision-making evoked re-engagement with the tablet, to move beyond the sharing of

ideas to creative thinking (Zurita & Nussbaum, 2004) and the exploration of conjectures in a non-judgemental way (Calder, 2011).

Whilst these social processes may be observed in classrooms without the use of tablets, the features of the tablets and apps alongside other media suggested affordances beyond that of just virtual and concrete manipulatives in relation to collaboration and suggested an inter-relationship between the multi-modal affordances of the tablet, along with other non-digital entities including peer interaction, concrete materials, and other pedagogical media. These inter-relationships are interpreted through the notion STA where social, concrete, and technical elements become merged.

The teacher Alan referred to a really big app ecosystem as students worked between different manipulatives and other resources, and his idea resonated with Meyer's (2015) suggestion that mobile technologies offer a socio-material bricolage for learning. The virtual and concrete manipulatives used interacted with the knowledge distributed across the learning site, with an interconnected system of material and social elements emerging (Meyer, 2015). In particular, the findings of this research indicated that there was specific interplay between the virtual and concrete manipulatives. The students moved between the two, possibly bridging from the more tangible, real concrete manipulatives to the dynamic, more abstract virtual manipulatives in connecting with abstract mathematical concepts and symbols. As such, the blending of the two may go some way to blur the distinction between concrete and abstract and shift to a relational view between concrete and abstract (Coles & Sinclair, 2019).

If viewed from Delanda's (2006) assemblage perspective, the learning experience becomes a social complexity constituted of heterogeneous entities, that are themselves assemblages. For example, students suggested social assemblages, such as the use of verbal language when communicating with each other or voice recording, but students also communicated through tapping on the screen or in sharing a document and referred to use of hand actions when using Multiplier or Tickle. As such, the multi-modal affordances of the tablet were used by the students to communicate and express ideas alongside concrete manipulatives and recordings. In this way, social and non-social entities could be seen to merge, and in line with Delanda's theory, the learning experience became a means of interacting with and creating new knowledge in ways that were determined by the features of the tablet as well as through other media and communication.

We suggest that the learning experience focused on engagement within an assemblage of learners, media, and the environment (e.g., Borba & Villarreal, 2005). This engagement reorganised thinking and provided fresh perspectives for re-engagement. As indicated by the students, they had opportunities to interact in collaborative ways to "work it out" and experiment, and to pause recordings in order to reflect before engaging further with the media. To interact with the mathematical ideas, students drew on existing knowledge and affective dispositions to engage with the mathematical ideas through not just the tablet but a range of social interactions that evoked interpretations or understandings that were negotiated further (Calder, 2011). Here the students were influenced by the tablet which they then influenced.

Our research question evolved from a quandary that emanated in one of our co-inquiry research meetings in considering how the affordances of a tablet app might have presented an alternative learning experience. We propose that an assemblage of social, concrete, and technical entities might form an alternative pedagogical media. For example, we would suggest that, when creating a screencast, there are opportunities for social and technical entities to merge in a way that would not be similar to a pen and paper activity. The content and nature of the screen-casting recordings were seen to merge the multiple modes of verbal expressions with drawings and symbols. Students created their own ways of expressing their knowledge using both social and technical entities. Furthermore, students usually developed these recordings collaboratively and acknowledged opportunities that enabled them to share and negotiate their knowledge in conjunction with the multi-modal affordances. Such recordings, compiled individually or collaboratively, would seem to illustrate the notion of STA that may influence the perspectives of those that viewed them, as well as those that created them.

On other occasions, students used an assemblage of concrete (e.g., rods, cubes, and whiteboard diagrams) and virtual (e.g., Minecraft) manipulatives in conjunction with social elements to negotiate their approach, thinking, and understanding. In these ways, the multimodal affordances of the tablet along with concrete manipulatives can be seen to provide new entities for social and technical to merge as an assemblage within a learning experience.

These examples of MT suggested that sharing and negotiation in conjunction with the multi-modal affordances was a means to interact with and create new knowledge. Hence, we propose that the notion of STA reflects the use of tools, MTs, apps, and haptic and social interactions that influence ways of engaging in mathematical activity, interaction with other students, and the potential for creating new learning.

Conclusions

In this paper, we aimed to consider how learning mathematics through MTs might influence learning experiences by examining teachers' and students' views in relation to the idea of STA and as evidenced in their classroom practice. The data generated through this research indicated that situating learning within a STA evoked a range of student articulations of solutions and thinking. Students created solutions using assemblages of social aspects, including collaboration and contestation of ideas, while exploring through digital and concrete materials and integrating these elements into their processing and presentations. Hence, the learning experience differed from using just concrete or just digital pedagogical media, and, likewise, students' understanding seemed to be different and positively influenced.

The idea of an assemblage suggests that the same mathematical phenomena can evoke different ranges of social and technical entities when approached through alternative pedagogical media, and the learning experiences, resulting from the merging of the different of social, concrete, and technical entities, will differ. The process of verbalisation, along with the manipulation of images, drawing, and other representations, would suggest a new learning experience: an experience situated within an assemblage of inter-related social and technical influences. Further study of the use of MT from an assemblage perspective could help us understand these influences and consequently to develop the use of MT to enhance learning.

Previous research has suggested that MT offers affordances that can reshape the learning experience. In this paper, we identified how teachers and students were using the assemblage of social, concrete, and technical entities to enhance the mathematics learning process when using apps. We suggest that teachers need to consider further the ways that they use educational technology in their mathematics programmes, not just to incorporate concrete and social aspects of learning, but to appreciate how the notion of assemblages can help to understand the potential for students to share, negotiate, and create new knowledge. While this study is limited to investigating assemblage in a specific subject, there is sufficient evidence to suggest that the findings could hold true for other curriculum areas. However, this aspect would require further focused research.

The application of the STA enhanced our understanding of learning with educational technologies, MT apps in particular, and helped to reveal some fresh implications for teaching practice. For example, how are teachers including screen-casting apps as an assemblage to both explore and communicate mathematical thinking? How are teachers using unplugged and plugged experiences for computational thinking? They might also utilise apps that include haptic and aural affordances as well as the more commonly recognised ones, such as linking multi-representations. Our research has suggested that such apps used with MT evoke collaborative aspects, including the potential to stimulate the contestation and validation of ideas and give opportunity for students to move between concrete and virtual manipulatives. As tools, MT has considerable potential for teachers to reshape the learning experience

and offer students new ways to engage with mathematics. This is consistent with expectations for teachers' programmes as expressed in national curricula.

Acknowledgements

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