Chapter X. Messing with Maltesers and magnets : Toward a theorization about affordances using tablet technology in inquiry teaching and learning

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Abstract This chapter is focused on discussion about the ways that tablet technology can support teaching and learning in inquiry contexts within STEM. The discussion about the nature of inquiry teaching and learning with digital technology is drawn from a series of case lessons in elementary science within the topic of 'Properties of Materials' in the UK. The research project informing this chapter examined teacher, young learners and non-participant observer's perspectives of the same events, namely two sequential science lessons one with and the other with-out the use of tablet technology. A socio-cultural perspective of learning was adopted. Reflections on these three contrasting viewpoints of the processes of teaching and learning informs a theorisation about practice that utilises digital technology. As Clarke and Svaneas (2014), Geer *et al* (2017) and more recently the OECD (2020) report, there is still no 'clear line' about which devices best support education, or indeed, how digital devices can be most effectively used. This chapter, therefore, offers suggestions about the ways that affordances or opportunities for young learners should be noted and pedagogically promoted more effectively in science inquiry situations.

Keywords: Tablet technology, Ipads, affordance, Science, inquiry

Introduction

Only within the latter half of the last decade has the use of tablet technology become a widely used resource for teaching and learning (Maich and Hall 2016; Chou and Block 2018) science. Despite the significant investment by Government, schools, colleges, however, there appears not to have been a commensurate theorisation of the ways it could be used for educative purposes. McFarlane (2019), in her relatively recent report, evidences how there is no guarantee that where technology is made available it necessarily impacts positively on learning. There also remains the challenge not only of embedding the use of digital technology (DfE 2019) across settings to ensure teachers consistently support learners to effectively develop digital literacy (OECD 2020), but also recognising what exactly teachers should pay attention to pedagogically to enrich and enhance inquiry learning. To effectively utilise different digital technologies requires different pedagogical strategies (Falloon 2017). For example, a stand-alone PC for each group of five pupils, or one laptop per child or one tablet per pair of students requires alternate teaching strategies to support effective learning. This chapter considers, therefore, empirical data drawn from studies of young students working in boy-girl pairings using tablets to suggest what an effective pedagogical approach to adopt is. Although the context of inquiry might seem very specific, there are findings that emerge that can be applied across STEM lessons utilising any form of digital technology. In investigating how the teacher and young students interacted with the technology to resolve learning tasks the juxtaposed understandings about how it can be used became apparent. This chapter therefore considers how, within the context of inquiry science, teachers and young students perceive and utilise the affordances that tablet technology can provide to augment learning. Interestingly, teacher's perceptions, learner's understandings and non-participant observer's views of the ways that digital technology can be used for learning do not entirely coincide. This presents a range of pedagogical implications.

Studies which focus on the affordances offered by tablet technology, such as the iPad, within specific disciplines suggest that there is an increase in cognitive, emotional and general engagement. For example, a teacher and teaching assistants, working with pupils aged 4 to 5, reported how it helped young learners understand key concepts and improved their communication, listening and fine motor skills within their numeracy and literacy lessons (Clarke and Abbott, 2016). Interestingly, young learners also intuitively appeared to have understood the purpose of the apps employed and how to navigate them (*ibid*). Additionally, apps can easily incorporate a range of multimodal communication tools to augment researching information, recording an investigation, capturing data, reporting on findings and generating a report on an inquiry. There are, however, reportedly over 500,000 apps available for teachers to choose from for a typical tablet. This only serves to exacerbate the issue of pedagogical decision-making about the best way to utilise technology in learning. However, within science education key iPad apps, such as Explain Everything (EE) are freely available and widely used. In the study reported on here, this flexible application allows teachers to invite their young learners to look at previously saved pictures, text and audio files, as well as provide a way of them [the children] archiving their own work in a range of visual, textual, audio and even videoed formats. The hardware of the iPad, and the EE software, as described in this chapter offer many different opportunities, or affordances for both teaching and learning. The ways that the iPad and EE were utilised, and extended affordances (Gibson 1977; Gomes 2014) for teaching and learning about materials and their properties within a series of science lessons was the context of the study reported on here.

Affordances, inquiry and theoretical framing of the study

This paper draws on an ecological perspective of affordances (Gibson 1977, p. 67) that reflects “metaphorically” the features or elements of a learning environment that comprises the classroom for learners and influences the processes they engage in. Just like particular habitats (like those in a classroom) have different places or niches for learning [like for example, a mobile trolley holding laptops, digital sensors or probes that can be used for datalogging or a specific corner providing preloaded reading on tablets] that offer quite different opportunities or affordances for learners [i.e.: digital probes monitoring environmental changes in temperature or reading text conveying important scientific information]. Having these different kinds of resources available influences the nature of activity and discussion that learners engage in. Considering contrasting materials such as a small A4 sized whiteboard and a dry wipe pen or an interactive whiteboard commanding half a classroom wall that responds to the contact of human digit provide contrasting media and physical space for an individual or whole class to relate to. When, for example, one learner is quietly working on sketching a diagram of their experimental approach or a whole class is collectively contributing to a tabular results table to provide an overview of many iterations of an investigation the processes of learning initiated are quite different. That is the affordances made available to learners differ. On the one hand the individual sketcher is focused solely on representing the equipment as accurately as possible within an A4 space, drawing with a coloured pen. The activity, thinking and discussion required for such will contrast starkly with the rest of the class collating and entering their data onto large sized spreadsheet. Learners interacting with each other through the medium of one tabular representation of the data collected by a whole class will require discussion, negotiation, decision-making and even metaphoric navigation to locate the correct cells for each data entry. Therefore, we are considering not only physical factors but also human interactions that affect or influence learning with tablets. This therefore resonates with the ecological view that multiple factors or elements, of both a physical and biological nature affect the way beings behave. The tablets [photographic facility, word-processing options, audio recording etc], the materials [maltesers, water, sand, salt, cups, spoons, etc] each contribute and interactions [of both actional and verbal nature] each in different ways conjure a classroom habitat that provides the environment within which the learning activity takes place. These multiple features, then, can be ‘seen’ or assumed to offer more or different forms of affordance to students depending upon the learning to be achieved.

Falloon (2017) introduces the way tablet technology, in the guise of iPads, was widely thought to be a ‘game changer’ (Geist 2011, p. 1, cited in Falloon 2017) because it was a portable and a mobile device that could ‘radically enhance student learning, by enabling them to collaborate and access information from anywhere at any time’ (Falloon 2017, p. 1). However, the most effective ways to adopt iPads (for example, for individual, small group or whole class activity; rotate sets around the school or provide dedicated devices for particular rooms) that maximises benefits for learning are yet to be clarified (McFarlane 2019). Technology, however, is recognised to offer a range of affordances (Gaver 1991) that can be utilised by both the teacher (Drennan & Moll 2018) and learners (Falloon 2017) in differing ways.

Adopting a socio-cultural perspective (Edwards 2000) of classroom activity that embraces the ecological perspective of affordances and values the interactions between teacher and students, appreciates the context within which they are working, attempts to make sense of meaning-making and takes account of cultural histories (Robbins 2003) is what we pay attention to. The focus of our research being concerned with ways that tablet technology extended affordances to enhance the quality of inquiry learning within the context of 'Properties of Materials'. In adopting a socio-cultural lens we were keen to consider the ways that the teacher and students interacted both with each other and the tablet technology and how peers worked collaboratively to resolve their scientific queries. Consequently, consideration of the ways that the technology supported and mediated learning processes, through the affordances it offered was key. Just as Norman (1999) distinguishes between 'real' and 'perceived' affordances, we recognised too, for example, that a digital screen allows the 'real' affordance of touching [or haptic experience]. Touch-screen enabled technology [a physical feature of the screen which allows the software environment to be controlled by touching] is adopted by tablet technology. The ways that touching in different forms [swiping, pressing, sliding for example] can then be considered as a 'perceived' affordance that tablet technology offers. Besides physical or 'real' affordances we also consider those that are 'hidden' [that is students working out what to do collectively to activate different facilities available on the tablet] may not so obvious, but these can be related and influential in STEM learning.

Through this series of lessons we offer illustrative episodes that present various ways that affordances of the technology and each other, as humans, were made available for learning. Through observation and discussion we were able to discern how the use of tablets was embedded within the socio-cultural practice that emerged within the particular science classroom episodes. We also consider how both the teacher and the students understood the nature of affordances that materialised for them during their joint participation in the scientific inquiries and through post-lesson discussions.

Adopting an ecological perspective of affordances

We adopted an ecological perspective of affordances (Gibson 1977, p. 67) that considers "metaphorically" how features of a [classroom] environment support learning. Applying this theoretical framing in a deductive way provides insight into what might be physical or biological that affects learning. We assumed the classroom, with scientific equipment and everyday materials provided physical artefacts for the students to consider and engage with. Just as particular habitats (that might be found in a classroom) have differing niches or places with which a learner can interact. The desktop computer providing a 'goto' reference corner; the iPads and sensors on the mobile trolley or the stack of kindles loaded with children's fiction on the shelf by the window each offer different affordances and potential for learning. The reference computer connected to the internet, with a shortcut to google, will offer quite a different opportunity to explore the world, compared with an iPad connected to a temperature sensor or a kindle offering a story about travelling to see the wildlife of Africa. Gaver (1991) suggests how it is not only what 'virtual' buttons [to press] are offered, but also how these are perceived or salient to users. A key element of identifying an affordance is when an action using an object is obvious in an immediate way with minimal mediation or voluntary sensory processing (Tinio and Smith, 2014). Users know what to do with an object without the need for instructions or labels (Norman, 1988), that is the object makes sense to them and affords salience. Culturally then technology and software that is regularly used, including particular 'tools' that are perceptibly available to the user as graphical (or visual virtual objects) become conventionally available and become a direct affordance for the receiver (Gaver 1991, p. 3). Thus, the affordances of technology are conveyed graphically [with visual aspects corresponding to different software features, like logging into an email system, the user develops familiarity] so that the 'attributes' of the system 'become available for action' (*ibid*).

The kinds of attributes that the combination of hardware and software on a tablet offer includes the ease of activating [through finger pressing, swiping and sliding] different elements of the software [which in this case is Explain Everything 2021] Using touch to select the various menu options from a word processor to create text, a camera to photograph objects or video events or even audio recorded reports of observations are salient for users who regularly use tablet technology. The ease with which users utilise these affordances can develop over time as they have become enculturated into routinely capturing their thoughts through tapping the word processor or selecting the camera icon to photograph a significant or notable event as it occurs. In other words, what the tablet technology offers is taken-up by the students, which in turn is shaped by their personal histories [and previous practices] of learning with technology. As Rogoff (1995) would describe, users appropriate a way of working with such an artefact, and intuitively and actively utilize what it offers them.

The use of the camera to video record observations, the audio-recording facility, all features embedded into the EE app are all forms of affordances of a haptic, visual and auditory nature. Besides the graphical or visual affordances that tablet technology offer, Webb (2005) also noted specific scientific affordances of technology including the ways that teachers framed learning tasks through the directions they provided that included instructions to think, predict, exchange ideas, investigate, compare, explain, apply and justify.

Students working collaboratively using technology can support an enculturated way of interacting. This promotes peer mediation of ideas and actions of and for each other. Therefore, as Gibson suggests that, ‘to perceive an affordance is not to classify an object’ (Gibson 1979 p. 134) or indeed, as Day and Lloyd (2007) affirm, it is not about just the inherent properties of technology that provide opportunities for learning. In this project the human or ‘hidden’ affordances (Achiam et al 2014) that are ‘perceptible’ and ‘offer complementarity of action’ (Gaver 1991) were also considered in the ways they were made available for learning. As Gibson (*ibid*), suggests, ‘The fact that a stone is a missile does not preclude that it can be other things as well. It can be paperweight, book end, hammer, pendulum bob. It can be piled on top of other rocks and make a cairn or a stone wall. …. Arbitrary names by which they are called do not count for perception’. The iPad and the EE app, therefore, offer more than the advertised functions, there are hidden affordances.

Students, therefore, engaging with the technology and working collaboratively on inquiry learning tasks, are thus presented with both physical and human affordances. As Gaver (1991, p. 1) describes ‘Affordances are properties of the world that are compatible with and relevant for people’s interactions’.

Scientific Inquiry

Inquiry has been globally recognized as an important learning experience for students in schools (IAP 2010; NGSS 2013). It is an authentic way for pupils to experience making sense of the world around them (Bevins and Price 2016; Braund and Reiss 2006; Roth 1995) and develop a better understanding of the nature of science (Erduran and Dagher 2014; Crawford 2000). It can also provide the opportunity for children learning science to become enthused (Minner et al 2010). Inquiry has historically held a coveted position in science learning, as Osborne (2014 : 579) cites Burke (1909) declaring, “I am convinced that the method of teaching which approaches most nearly to the method of investigation, is incomparably the best…… it tends to set the reader himself in the track of invention, and to direct him into those paths in which the author has made his own discoveries”.

The policy in the English National Curriculum, outlining how students should work scientifically (DfE 2014) in schools, identifies particular kinds of inquiries that should be offered in schools, including :

- observing over time;
- pattern-seeking;
- identifying, classifying and grouping;

- comparative and fair testing (controlled investigations); and
- researching using secondary sources.

It is suggested that, through these kinds of experimental approaches children will become equipped with the scientific knowledge (and skills) to understand the uses and implications of science, today and for the future.

Pedagogically, Harlen (2014) identifies how the development of the kinds of inquiry skills outlined above with younger pupils, particularly, presents a range of challenges for teachers. Inquiry, she argues, extends well beyond just 'practical work' or 'hands-on' experiences and is not just concerned with children 'discovering' for themselves, but is concerned with the development of an array of skills. The particular abilities that Harlen (2014) highlights include:

- raising questions, predicting and planning investigations;
- gathering evidence by observing and using information sources;
- analysing, interpreting and explaining and
- communicating, arguing, reflecting and evaluating.

Ofsted (2013 p.10-11) recognises that these types of skills, including pupils evaluating and drawing conclusions from their science work, is limited and that this, particularly in primary schools is underpinned by teachers' lack of expertise. Evidence of this kind suggests how there are lingering issues with inquiry, not least that teachers do not fully understand and appreciate the nature of it (Minner et al 2010); that they often (unwittingly) provide far too much 'help' and 'support' in the preparatory activities for carrying it out (Johnston 2007) and thus 'lessen' the cognitive and affective demands of it…and perhaps even render it more of a 'verification' activity; or conversely they may elicit a range of burgeoning questions and queries from the children or students and then 'prescribe' the best way for the whole class to investigate one of the emergent questions. Therefore, the extent to which inquiry skills (of aligning a query, developing a rigorous plan to investigate it, independently collecting evidence and then synthesizing meaning from the data) may not be fully developed or key elements may be missed.

Teachers reflectively, can mis-understand and/or mis-judge their pedagogic aims (McMahon and Davies et al 2003; Johnston 2014). Appreciating the 'real' extent to which autonomy or agency is afforded to the learners, can range from very 'teacher-directed' or 'teacher-led' as in a closed inquiry, intended to demonstrate or practice a particular inquiry skill, through to 'teacher-guided' or, at the other end of pedagogic spectrum, an open inquiry that is entirely 'student-led'. Tablet technology affords a range of opportunities for pupils when carrying out inquiries (McGregor, Bird, Frodsham 2016) to work independently of the teacher. They are able to collaborate, make-decisions about data collection and analysis, become reflective and reflexive (altering their method or analysis as appropriate) because, for example, they can easily 're-wind', review, reorganise or re-record their experimental work on the tablet.

In this study, we were keen to elicit how the teacher perceived the affordances of the tablet technology and organised ways of working for the students within the classroom setting. We also explored how the students, in turn, understood the affordances that the tablet technology made available for them. We acknowledge that we focused on classroom dialogue because it is highly relevant, but we also paid attention to the nature of interactions [with the technology and between peers] to inform how the learning discourse emerged (Rogoff, 1995, p. 142).

The research concerns that were uppermost in our minds involved exploring how teachers' and students' experiences and understandings about how the utilisation of tablet technology for scientific inquiry differed. We were also interested in lesson enactments that illustrated how the affordances were made available and utilised. Finally, we were interested in whether there were any recommendations, emerging from this study, for teachers organising classroom settings that utilise technology to enhance STEM inquiry learning?

Methodological approach

This research was carried out within a qualitative-interpretive paradigm. This approach was adopted to help make sense of the everyday and socially complex world found within the educational environment (Merriam and Tisdell, 2015). The aim being to explore the nature and uptake of the perceived and hidden affordances in inquiry contexts. A range of research methods were utilised to probe (Mitchell 2006) the nature of learning with and without the affordances that tablets provided. We also examined the way the teacher's approach framed and mediated eight year-olds carrying out inquiry activities involving practical tasks that challenged them. The young students were tasked with finding out what they could about the properties of different materials (e.g. maltesers, rice, pasta, soil, magnets). They were provided with some scientific equipment including a sieve, funnels, filters, a magnet, jars and the EE app to record their investigation. Reflective discussions with the researchers after the series of lessons involved explored how the teacher and student perspectives of the use (and application) of iPads and the EE app in science supported both teaching and learning. With a focus on physical and hidden affordances, as elicited through the participants vocalised thoughts the data was collected and subsequently analysed over two 90-minute episodes to answer the research questions. They were :

How does access to tablet technology affect the nature of teaching and learning in a STEM inquiry?

How do affordances offered through using tablet technology within a STEM inquiry support learning?

Research Design

To respond to the research questions the impact of learning *with* and *without* an iPad was examined through a comparative case study approach.

That is, two lessons based on the topic of *Materials and their Properties* were videoed (one was a hands-on inquiry, without any access to technology and the other involved the use of tablet technology and the EE app). In the lesson, where iPads were provided for the students who worked in pairs, sharing a tablet between them. Contrastingly, the other lesson without the use of the iPads, was structured in such a way that the pupils had the same set of apparatus but only their science books to write notes, observations and their results. Both sessions invited the same paired pupils to separate a pre-prepared mixtures. In both lessons they were challenged to separate different mixtures. The substances in the first lesson included milk, rice krispies, salt and iron filings. The substances in the second lesson included water, maltesers, lentils and sand. Setting up similar situations for learning in sequence to contrast the nature of classroom interactional processes has been applied previously (McGregor et al 2020).

Participants

The study reported here involved a class of 30 young students in an elementary school in Oxfordshire. The school was large, with over 300 students from age 3 – 11 years. The ethnic make-up is 80% White British with other smaller proportions of Irish, White and Black Caribbean, African and Asian descent. It was Ofsted (the National Office of Standards in Education) rated ‘good’ (Ofsted 2017). The class involved participated because the teacher who was the ICT co-ordinator, had in the previous year embedded the use of the iPad tablet and the software, the EE app, into all her teaching. Therefore, the whole of the mixed-ability class, in year 4 (when they were eight/nine years old) became conversant with adopting the technology whatever they were learning. The whole class were observed naturalistically over the two lessons (amounting to around 180 hours). To provide more specific details about the observed processes of teaching and learning, video cameras were set-up around the perimeter of the room with a view to being able to watch more closely (focus on dialogue and inter-action) 3 different pairs in the class. The teacher and those more closely observed young students were interviewed after the videoed lessons with a view to exploring how they each understood the iPad (and the EE software) had afforded opportunities to engage in the scientific inquiry tasks.

Data collection

This took place in two phases. The first phase involved lesson observations, not only of the students, but also the ways that the teacher conducted the various stages of the inquiry activities. These were all captured via video and audio-recordings. The second phase involved interviewing both the teacher and some of the students after the lessons had been observed.

Observations (classes with and without tablet technology)

Observations of the two science lessons focused on scientific inquiry that were sequentially taught within the topic, 'Materials and their properties' were carefully framed. This included the students being invited to examine a range of mixtures, dissolving different solids in solutions and also separating solids and liquids). During the latter science lesson all 30 students were invited to use the EE app, pre-installed on their iPads, to capture photographs of their experimentation, record events through the videoing facility, note changes numerically to graphically present changes, audio-record their discussion about their own findings and collate all the different media forms by which they enacted and interpreted what they found within an EE file. One iPad tablet was provided for each girl and boy pairing. After the lessons, the EE files were uploaded to a class dropbox, for the teacher to feedback on. The science lessons, and more specifically three pairs of boy-girl couplings, were videoed and each of the six pupils also carried Dictaphones in their pockets connected to lapel microphones. The student's interactions were captured audibly and on video because, as Brown et al (2016) noted there was a need for us as researchers to understand how students conceptualised and pragmatically utilised the digital technology. The video and audio data that captured a clear chronology of activities in the two lessons, with and without the students using tablet technology was fully transcribed and annotated so that the socially complex worlds could be made visible through forms of co-constructive (verbal and actional) interactions (Denzin and Lincoln, 2008). This was a necessary step because, not only is there a paucity of research involving the direct observation of the use of iPads in the classroom (Bixler, 2016), this rich data set could examine the nature of the interactions and affordances offered between the pupils and their shared tablet technology as well as suggest how a lack of technological support affected inquiry learning.

Interviews

Post-lesson audio recorded interviews provided interviewees' perspectives regarding implicit and experienced affordances offered via the use of the tablets and

EE. Perspectives were elicited from both the teacher and students to explore how and if their understandings about technological affordance in inquiries differed. The teacher was interviewed independently, away from her class. We were not solely concerned with the teacher's perceptions of inquiry learning with and without tablet technology. However, her views about the progress of the young students in her lessons and the different ways she had scaffolded inquiry activity with and without technological support was of key interest.

The six pupils, observed most closely, were interviewed in their pairs after the lessons, so that their recollections and understandings about the use (or lack) of technology would flow and emerge more naturalistically, enabling them to collaboratively spark off each other's thoughts and memories and provide a more in-depth description of events. The questions they were invited to respond to related to their experiences of using an iPad (or not) during their science lessons. Semi-structured interviews have previously illuminated secondary school teacher's views about the integration of these hand-held devices (Lewis, 2018) and they have previously proved insightful when contemplating how primary and secondary teachers' have employed iPads in their classrooms (Vu, 2013, Hilton, 2016, Jack and Higgins, 2018). However, there are relatively few reports of the student's own perceptions of digital technology relating to the utility of iPads using this method of data collection. That is, when students were invited to articulate their views on this subject it was reportedly collected through questionnaires (Soffer and Yaron, 2017) and not interviews.

The semi-structured interviews with both teacher and paired pupils included 16 and 11 open (verbal) questions respectively, which were designed to explore resonance or juxtaposition in their perspectives of tablet affordances. The teachers' questions focused on the general use and advantages of the iPad for teaching science; how they believed the affordances offered by the iPad augments scientific learning; what they thought the EE app offered the teacher and the pupils; and explored what the teacher considered was omitted when the iPad and the associated apps is not used during the science lesson. The pupils were invited to answer questions related to the nature of the affordances (actional and verbal) the Ipad and EE app offers and how this help them learn science; what the difference was between learning science with and without the iPad and what they felt they missed out on when they did not use an iPad.

The teacher and pupil views (from both data sets) were subsequently triangulated to corroborate any articulated illustrations of the affordances offered when teaching and learning science through this technological interface. These interviews not only allowed for a comparative case study between student pairs and the teacher, but also enabled the justification and tentative validation of views which related to the direct impact of the iPad in a primary school science lesson.

Data analysis

The dialogue in the lessons that was audio-recorded during the lessons, the post observational interviews and those that took place during the science lessons were all fully transcribed and analysed through four phases.

i. Observational analysis was both inductively and deductively analysed. For the inductive analysis a timeline of teacher and learner events was collated. For the deductive analysis an analytical framework that identified the nature of affordances, physical and material (Gibson, 1977; Norman 1999; Hammond 2010); pragmatic and sequencing relating the geometric (Achiam et al 2014) and Hidden, both intentional and cognitive (Achiam et al 2014) was applied to the observations noted.
ii. Dialogic analysis focused on talk between the teacher and learners (Alexander, 2008).
iii. Deductive analysis of the dialogue between the paired students. This was considered inductively and deductively (for different types of talk including disputational, cumulative and exploratory (Littleton and Mercer, 2013).
iv. Reflective interviews with the teacher and learners (eliciting their views about the ways the iPad offered affordances) were also deductively analysed by adopting the same analytical framework as described in phase 1.

In summary the initial examination of data was inductive, that is, the transcripts from all four interviews (One teacher and three pairs of children) and the observations were thematically analysed (Braun and Clarke, 2006). Finally, they were inspected (and coded) for various affordances offered by the iPad, namely: sensory, cognitive and physical-geometric.

This enabled the establishment of clear links between the research questions and the summarised research findings below (Thomas, 2013). That is, the synthesis of fuzzy generalisations (Bassey 1999) were suggested [because this is an exploratory study, not a positivist one involving the collection of numerical data that could be statistically analysed]. The data relating to the impact of the iPad and the affordances that were offered by the use of these hand held devices [has been proposed through synthesis of data that informs Figure 1] when considering teaching and learning science, from not only the teacher's perspective but also their pupils.

Ethics

Ethical approval was granted at university faculty level and consent from the school was sought and obtained from the Headteacher, teacher, parents and the young participants. Prior to the interviews, consent forms were signed by the teacher and the parents, on behalf of the child.

Findings

In comparing the science lessons with and without the tablet technology it became apparent that there were notable differences in the ways that the teacher prepared for the practical activities and also the ways that the students engaged with scientific inquiry (see table 1).

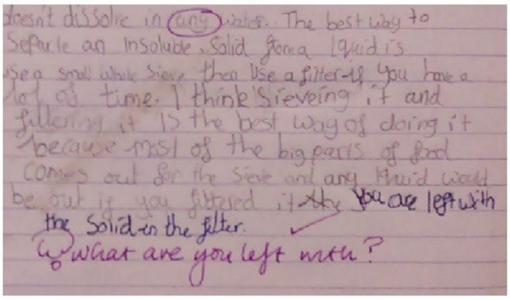
Table 1. Relative differences noted in contrasting the two lessons with and without a tablet.

Forms of student engagement	**Lesson without tablets available**	**Lesson with tablets available**
Time spent discussing ideas	Less	More
Time spent writing	More	Less
Time spent quietly working solo	More	Less
Time spent collaborating (i.e.: inter-acting to achieve the learning task)	Less	More
Time spent videoing/ photographing	Less	More
Time spent manipulating report on tablet	N/A	More

The forms of engagement identified in table 1 above, when the data was scrutinised more closely, also illuminated how the nature of talk differed, the extent of scientific thinking appeared to be constrained without the iPads, and how the quality of hand-written reports was much briefer and less detailed [in a methodological, observational and interpretative sense] than the EE files produced (see Figures 1 and 2).

A mixture is two or more objects (food) that are combined together which can separate. A soluble solid is a solid that dissolves in cold or hot water. An insoluble solid is a solid that doesn't dissolve in any water. The best way to separate an insoluble solid from a liquid is use a small whole sieve then use a filter if you have a lot of time. I think sieving it and filtering it is the best way of doing it because most of the big parts of food comes out for the sieve and any liquid would be out if you filtered it. [You are left with the solid in the filter].

Fig 1. Excerpt from Student A's exercise book.



Transcript from Clarkes Science book: 'The best way to separate [sic] an insoluble Solid [sic] from a liquid is use a small whole [sic] sieve then use a filter if you have a lot of time. I think sieving it and filtering it is the best way of doing it because most of the big parts of food comes out for the sieve and any liquid would be out if you filtered it. You are left with the solid in the filter'.

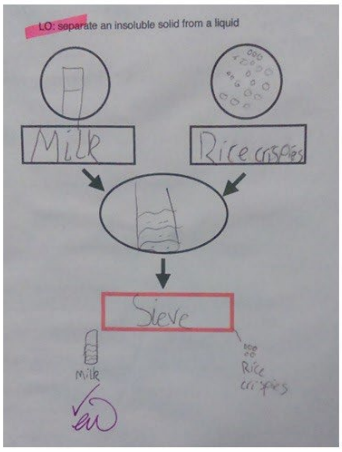


Fig 2. Excerpt from C's exercise book.

This is in stark contrast to the quality of observation, reporting and conclusion-making that was evidenced in the lesson through the portable digital technology, via the EE app.

i. Differences in the nature of talk, both between the students and the teacher and the learners.
ii. Evidenced differences in thinking
iii. Quality of reports produced
iv. Contrast in pedagogic preparation.

The types of open-ended tasks, offered through the embedded application promoted opportunities for exploratory discussion; this was reportedly because the pupils were also afforded the opportunity to work more collaboratively and independently of the teacher. That is, the digital assist appeared to enable groups more time and space to develop and apply a wider range of scientific explorative strategies. The lesson where digital technology was not available appeared to be less thought provoking with the children heard nominally talking about equipment to use and its location.

The teacher also noticed how her preparation differed for the two types of approach. The way she engaged the pupils in thinking about inquiry was constrained without digital technology. She realised that utilising the exercise books as the record of the planning and experimentation distracted the children from the science because they were more concerned with writing rather than thinking and doing. She also noted that learner agency was more effectively promoted because the children were more able to work independently.

The students' post-lesson reflections on learning with the technology supported the notion that they were more agentive, and felt more extensively in control of their science endeavours because they were afforded both cognitive and material (and physical) learning opportunities. Therefore, the iPads afforded opportunities beyond that which they experienced with only the exercise book and science apparatus. They appeared to feel they were acting and thinking more scientifically when armed with digital technology.

Interestingly, the third perspective or the non-participant observers noted additional affordances that neither the teacher nor the children paid attention to.

Observations of the learning with and without a tablet

In both the lessons observed, there was much practical activity as indicated in Figure 3a and b.

Fig 3a and 3b. Indication of the nature of practical activity undertaken

In the lesson without the tablet technology the students spent much more time writing in their exercise books. Interestingly, the scientific vocabulary, the details of their own inquiry observations and the extent of their thinking was not reflected in these hand-written reports. Although the students were accustomed to documenting the work, their written work in the lesson without the tablet technology was much more limited (see Figure 2 and 3). However, the nature of reporting was much more varied in the EE files on the tablets. They included photographs, video clips, audio and textual explanations in the inquiry reports (as indicated in Figure 4a-d).

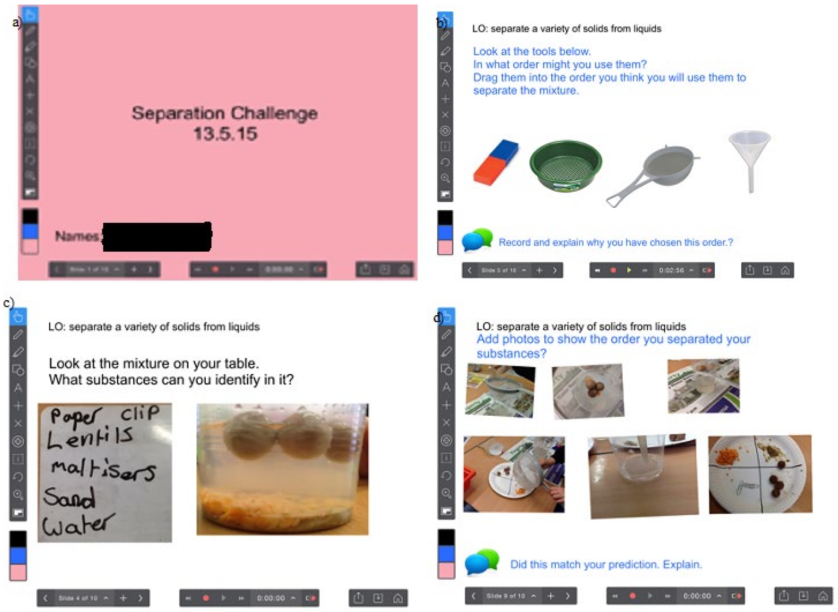


Fig 4a, b, c and d. Excerpts from Student B & C's EE file. Indication of the range of different kinds of information in it.

Contrasting the nature of talk in these lessons, with and without tablets indicated there was less general discussion (which was confirmed by analysis of the lesson transcripts) and more quiet individual working when the students did not have access to the tablet technology.

From analysis of the lesson transcripts (with comparative excerpts provided in Table 2), it became clear that, when the tablet technology was not available, there surprisingly appears to be more "I think …..' and …'because…' (Mercer 1999) comments exchanged between learners. Deductive analysis involving examination of the kinds of utterances exchanged between the students indicated to some extent how they, i, worked together (through analysis by applying Mercer's three types of talk, disputational, cumulative and exploratory), and, ii, what kind of collaborative co-constructive thinking they were engaging in (Littleton and Mercer 2013).

It was intended that this analysis would shed light on the nature of speech-acts the students engaged in and whether there were notable differences when an iPad was the medium by which the inquiry activities were documented. The analysis looked at three kinds of talk, informed by Mercer (2008), considered firstly 'disputational' discussion characterised by a lack of shared perspectives or 'constructive criticism' (Mercer, 2008:1) that often features one dominant voice. Secondly, 'cumulative' talk, whereby 'everyone simply accepts and agree[s]' with what the others say, in doing so they make what they think available for others, but they do so in an uncritical way lacking elaboration and evaluation. Thirdly, 'exploratory' talk was also considered, that is dialogue whereby the exchanges make explicit alternate views and justifications that may even reach an agreed perspective (Littleton and Mercer, 2013). Interestingly when tablet technology was absent, there was much less questioning of each other, but the more disputational type statements, including the 'I think…' and the 'because…' claims. The discussion focus was centred more on what equipment they needed (such as, filters, funnels and sieves) and where to get it from. The transcriptions indicated how scientific terminology was used much more apparent in dialogue between the pairs of students using tablet technology. However, when using a tablet, there appears to be less "I think …..' and …'because…' comments between the pairs of students. With one pair, 'I think…' was only uttered twice and '..because..' was only used twice. However, when the dialogue was analysed for verbal exchanges that demonstrated asking each other open questions (Siraj-Blatchford and Manni 2008, p. 14) there was more dialogue that demonstrated questioning each other about aspects of the task, including how they carried out the method and how to best explain and capture it through pictures, or video, text and audio. The proportional utterances of scientific words in context was less, but overall there were more words exchanged in the lesson. A breakdown of the frequency, or overall percentage, of these types of verbal exchanges, from the transcripts, can be found in table 2 below.

Table 2. Example of comparison between the same pair of students, with and without the tablet available.

Types of verbal exchanges	**Without tablet available**	**Frequency tally**	**With tablet available**	**Frequency tally**
'I think…' '..because..'	I think …. Because …..	9 3	I think …. Because ….	2 2
Questioning of each other	Student C Student A Total no. of Open questions	6 7 6	Student C Student A Total number of open questions	22 37 59
focus of exchanges	'filter' 'funnel' 'sieve'	7 1 5	'filter' 'funnel' 'sieve'	12 2 16
Total words uttered during lesson	In 1 hour; 20 minutes	2391	In 1 hour; 17 minutes	3321
Reflection within talk	45% of talk	1075	55% of talk	1827

Teacher Interview

The interview with the teacher elicited a range of perspectives not only about how she used iPads specifically for teaching the science lessons we observed, but also about how tablet technology supported learning generally. Interestingly she explained how, for inquiry science, the tablet, 'allow[s] them to review not just what they've done but I think it allows them to, if you've given them some stimulus allows them to predict. So, I think it's […] personalising their views on what is going on because if I just show one thing on the board it's not quite as focused as two children focusing on something in-between them that they've then got that ability to talk [about]'. She then shared how, even if she used technology of a different kind it didn't necessarily scaffold the young students working independently. She stated that, 'If I just do a powerpoint I can skip through it, I'm in control'. She was very aware of generating opportunities for all students to engage in the inquiry activities, she explained, 'If I'm more specific about what I want the objective to be, also […] thinking more clearly about the differentiations […] of children who can't read, who can't access, who […] don't have a background knowledge that they can bring to help and I give that to them, […] I allow them to access things in, in a similar [way] or give them something that allows them to almost catch up where I know those other children potentially are. Then […]they're working through more independently.' She recognises, too how being able to work independently is important pedagogically, through the way she 'sets-up' the tasks 'without being too prescriptive, so I don't want them to work only to provide answers', she designs the activities so that they are 'a little bit open ended'. She also appreciates how the tablet technology enables and supports development of many aspects of scientific inquiry, like, 'making systematic and careful observations'; 'gathering, recording, classifying and presenting data in a variety of ways to help in answering questions' (DfE 2014, English, National Curriculum), through the technology allowing varied ways of visually recording and presenting videoed or photographed reactions or events. She says, 'because of the ability to slow things down. I think, you […]put it in video, the video you can slow mo it. So, for example two liquids mixing food colouring and water or even, even a solid like coffee granules and water, it's, it's ten seconds and the coffee granules are dissolved and you've got a solution haven't you […] so, it's the fact that they could slow it down and see that as the coffee granules were dropping actually they were starting to dissolve already', 'they notice odd things' and 'more scientific explanation [can] come from someone else rather than me'. The use of the iPads, was recognised by this teacher to offer (different layers of) affordance for her learners. She recognised that within the process of learning, the tablet technology afforded :

- Ways of being reflective about learning experience(s) to explain what has happened or what has been done;
- Ways of 'transforming' their thinking (about science) for different audiences [themselves, each other and the teacher];
- Ways of replaying happenings and/or events including changes of state, dissolution, evaporation etc;
- Ways of reviewing the claimed outcomes of experimentation;
- Ways of verifying if others have found similar behaviours of materials;
- Ways of reporting the outcomes of inquiry activity that affords more personalisation of the science.

These resonate with Drennan (2019, p. 42) who, as a researcher eliciting how tablet technology afforded effective pedagogical use, highlighted *reflection*, *transformative teaching*, *generative activity*, *situatedness* and *appropriateness* of ICT use.

As Drennan (2019, p. 42) suggests, it is the way the teacher uses the technology in their teaching, not the 'what they do'. In this study we are emphasising the outcomes from learning similar subject matter with and with-out the use of technology. This suggests how pedagogically the teacher made a particular range of affordances of the technology available for the students to utilise for learning.

Students' views elicited through interviews

After the lessons which were observed, the students were asked about the ways they thought the tablet technology helped them learn in science, especially inquiry activities. In summary the kinds of affordances they paid attention to included how the combination of hardware and software enabled them :

- To find about things they were unsure about [via the internet];
- To check and verify their understanding of scientific words [via the internet];
- To collate useful library images when need to generate illustrations;
- To be able to easily plan, explain what done [with different equipment], the steps in the inquiry;
- To pay more detailed attention than normal to the sequence of activities;
- To take lots of photographs of what was being done (and upload to dropbox);
- To use audio-recorded speech to verbally explain what was done;
- To annotate diagrams explaining what was done.

The specific kinds of comments they made are included in a summary table (see Table 3) of affordances.

Discussion

Within a socio-cultural perspective of learning, the tablet technology offers affordances that promote working scientifically (and consequently enable enhancement of inquiry skills and understanding of aspects of the NOS).

The teacher recognises that the tablets support more in-depth and focused reflection on scientific phenomena for the students when they are engaged in inquiry learning. It is notable that reflections evidenced from the transcripts [researcher's perspective] as indicated in Table 2 illustrate how tablet technology affords more interactivity between learners demonstrated by the increase in open questions exchanged, the focus of scientific exchanges and the extent of talk concerned with scientific method, explanation of inquiry and varied means [photo/video/text/audio] by which they record the events of their experimentation. The nature of the students' talk is more exploratory, that is asking each other about what they think, rather than disputational whereby one student's views, directions and actions predominate over another. The teacher's comments in the interview verify that iPads can promote scientific literacy and a general increase in discussing aspects of scientific inquiry. Although the teacher recognises the review and recounting process scaffolded by the iPads, the researcher perspective offers more in-depth detail because the transcripts offer evidence of the nature of dialogue rather than re-collections of it. The transcripts from the student's audio-recordings also allow analysis of the use of scientific terms and whether or not they are applied in context and consequently offer examples of scientific literacy.

In contrast the students focus a little differently on the affordances iPads extend to them. Their juxtaposed perspective indicates how as users of the technology we [teachers and researchers] should take account of their views (Ruddock 2007). They appreciate and understand how different aspects of the physical environment generated by the technology (tablet and EE software) affords different kinds of possibilities. These are summarised in Table 3.

Table 3 : Student's views of affordances offered through the use of tablet technology and EE software.

Physical attribute provided by tablet (and EE) in the learning environment	Generalised nature of affordance	More specific inquiry learning and learner affordance	Related student comments
Small size and long battery life (portability)	Learning can be ubiquitous, flexible and polysynchronous (not time bound)*	Data can be gathered anytime, anywhere about almost anything within the classroom.	"pairs better than as individual (think harder on your own)..and quicker if work together"
Touch screen	Fingers control use (no peripherals like mouse, keyboard etc).	Easy manipulation to engage in different aspects of inquiry including; i. observation over time; ii. looking for patterns; iii.identifying groups or classifying objects or events; iv. compare or contrast things	"move pictures around easily" "enables personalized way of working" "offers customized learning resource" "more at hand (don't have to fetch books).. " "do things quicker"

		and research existing data sources.	
Intuitive interface	Easy manipulation by tap and swipe. Learn through using the technological capability, not learning about how the technology works.	Immediate data capture in a variety of forms that can be manipulated into illustrations, video, photos, textual or tabular forms, graphical displays etc.	"everything just there'" "Search better words" "flexible to change things" "can verify words/terms/objects don't know/not sure about"
Integrated audio and video software that enable multi-media software (EE)	Various visual affordances [video/photographic/images/texts]; i.Video recordings ii.Still photographic recordings iii.Replay and slow-motion re-viewing of events and phenomena iv.Audio-digital recordings v.Textual input Other sensory [auditory and haptic] affordances	A range of inquiry practices supported including; i.Raising questions; ii.Gathering evidence; iii.Analysing, interpreting and explaining; iv.Communicating, reflecting and evaluating.	"if don't have ipad cant film it – like chocolate melting…if you have to remember it – it just goes out of your head!" "with ipad don't have to remember what you say to write it – can record it frustrated if don't have an ipad" "correct mistake (or something wrong) more quickly" "instead of writing can talk it" "neater writing/text to explain/describe things/what done" "record sound/voice" 'zoom' in on things to see more detail"
Connection to Apply TV	Easy whole class viewing of same screen	Whole class viewing to verify and validate nature of a range of inquiry practices (see above).	'zoom' in on things to see more detail"
Connection to dropbox	Easy exchange of large multi-media EE files	Learning from each others' inquiries.	"remember/archive stuff (in dropbox)"

*Excerpt from Drennan and Moll 2018, p. 125

Conclusion

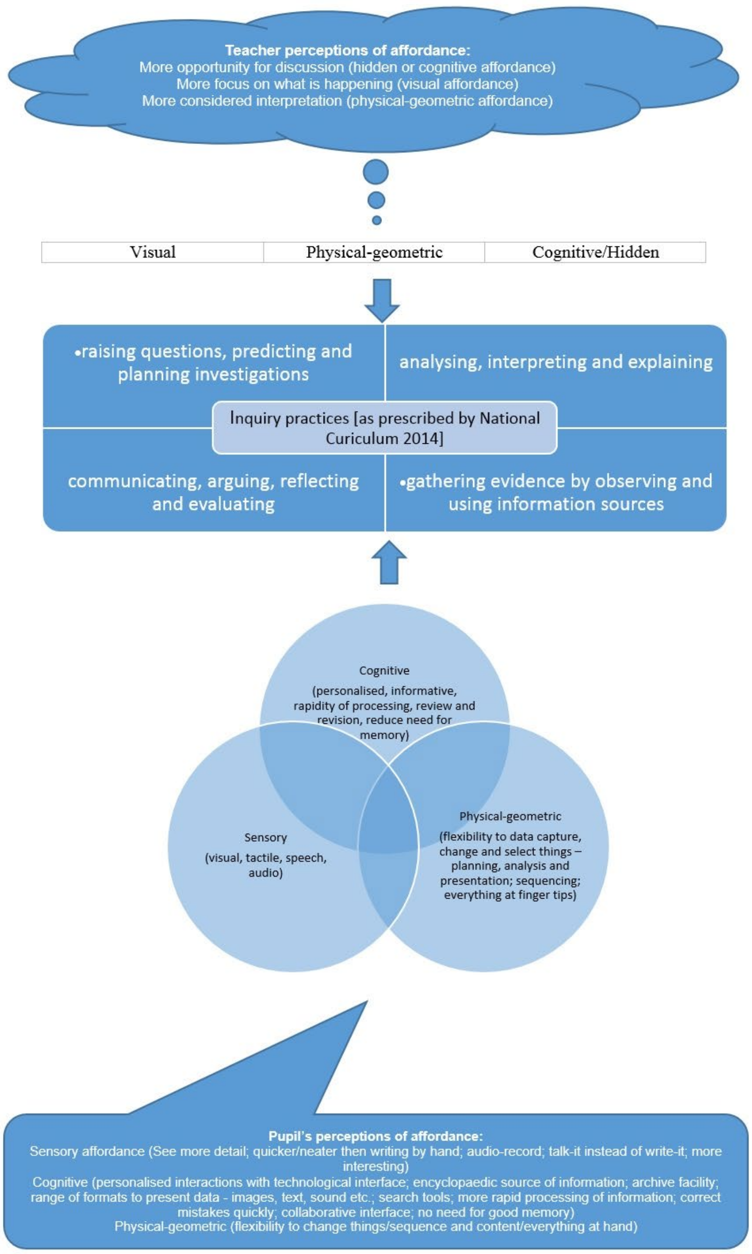
So, although the practitioner's reflections, researcher's observations and students' views differ a little in focus there are key common features emphasised that tablet technologies offer when learning about and through inquiry. Table 3 summarises a range of ways in which inquiry practices can be engaged in (and are even recognised by the students). Interestingly though, in discussion with the teacher and her students, there were some differences in the ways affordances for scientific inquiry were perceived. We offer a model (Figure 5) that suggests how teacher and student views relate but also differ.

Digital technology involving touchscreen, photo capture and audio recording that can be easily integrated offers enhanced sensory, physical-geometric and cognitive affordances that can enhance inquiry learning in STEM. It would be helpful for teachers to be aware of these and consider carefully how they make them available without prescribing how to use them.

Interestingly, this model could not be conceptualised without the data collected from the three juxtaposed perspectives of teachers, young learners and non-participant observers to develop and offer a proposition about the ways that digital technology can augment learning.

This exploratory research offers insights that are useful for pre-service, in-service teachers, teacher-educators, researchers and policy makers who influence ways resources are made available, provide curricular guidance about how to use technology and mediate ways beginning and qualified practitioners develop their practice.

Figure 5 : Teacher and students' contrasting perspectives of affordances offered through tablet technology.



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