Using digital technology to enhance formative assessment in mathematics classrooms

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Abstract

In this paper, which is based on research from the EU-funded project Improving Progress through Formative Assessment in Science and Mathematics Education (FASMEd), we explore how iPads are used within formative assessment processes by six mathematics teachers and their classes in two secondary comprehensive schools in the Midlands of England. A design research approach is first used to develop and trial six lessons in which iPads are used in different ways within formative assessment processes. Through lesson observations, video analysis and teacher interviews we then examine how iPad technology contributes to these processes, the functions it performs and the distribution of activity between the main actors (teacher, technology and student). An analytic approach is developed which captures the interactions in visual representations, showing how the technology is often used as a form of communication but also performs more active functions which affect the role taken by the teacher in formative processes. The study offers insight into ways in which iPad technology contributes to effective student learning through formative assessment and introduces an analytic approach that may be useful for further studies.

Key words

Digital technology, iPads, mathematics, formative assessment.

Introduction

The technological developments of the last few decades have undoubtedly prompted a cultural revolution affecting our social habits, communication and work procedures (Vander Ark, 2011). In particular, the expansion of digital technology has led to a proliferation of static and hand-held devices with networking and information sharing capacities. A significant impact on education might be anticipated from this technological revolution (Yang, 2013), particularly when learning is viewed as a socially situated practice, since digital technology provides new methods of communication and social interaction. The adoption of technology within the classroom does however fall short of expectations (Fullan & Donnelly, 2013; Livingstone, 2012; OECD, 2008) and pedagogical adjustments by teachers to the rapid changes in technology seem to proceed slowly. This apparent reluctance on the part of teachers may be attributed partially to external constraining factors (Hennessey et al., 2005; Yang, 2012) and the slowness of system change (Fullan & Donnelly, 2013) but raises questions about whether evidence of the benefits to student learning are sufficiently convincing (Livingstone, 2012) for teachers to change their established classroom practices. For pedagogical change to be achieved, it seems that a better understanding of how technology contributes to effective learning processes is still required.

According to Higgins et al (2012), the pertinent question to ask is not *whether* digital technology is being used but *how* its usage supports teaching and learning. We consider therefore how digital technology is used by teachers and students and becomes a ‘tool’ that “supports and shapes learning” (Loveless, 2011, p.306). Our focus for this research is on the affordances of iPads within formative assessment processes in mathematics classrooms, when used, by teachers and students, with several types of software that were available in the participating schools at the time of the study. We describe these in more detail later but will hereafter use the term ‘iPad technology’ to refer, in a general sense, to the combination of iPad and software.

By designing and analysing lessons in which iPad technology is used within formative assessment, we aim to better understand the interactions of teacher, technology and student and the contributions of iPad technology to formative processes. Our examination of this specific classroom practice, which Black and Wiliam (1998) claim has a positive effect on student learning, enables us to focus on these interactions and the ways in which iPad technology contributes to effective learning processes. The research reported here seeks to address the following questions:

- What functions does iPad technology perform in formative assessment?
- How do these functions contribute to formative assessment processes?
- How are formative assessment processes distributed across the main actors (teacher, students, technology) within lessons?

Existing evidence suggests that using tablets to support learning can enhance student learning outcomes but that the research base is fragmented (Haßler et al., 2015). Looney (2010) however identifies some key functions of technology that can support formative assessment processes, including rapid assessment, timely and targeted feedback, interactive learning, assessment and tracking. This suggests that iPad technology might perform some useful functions with formative assessment and contribute to student learning but does not explain how effective processes involving teachers, students and iPad technology are constructed.

Background

In view of the limited number of classroom studies of iPad technology, we will first consider some of the relevant themes emerging from the general literature regarding the use of technology within classroom teaching. This is followed by an examination of formative assessment (Black & Wiliam, 1998) as a socially situated practice, in which we highlight the main features of effective processes.

In general, although there is research evidence that suggests positive benefits from using technology, it is difficult to draw strong conclusions about classroom use. Whilst some research provides evidence of learning gains (Higgins et al, 2012) and supports claims that technology can promote deeper learning (Vander Ark & Schneider, 2012), other studies are less conclusive (Haßler et al., 2016). Some of these variations in effect may be due to differences in the way the technology is used (Higgins et al, 2012) or in the pedagogy that teachers employ (Fullan & Donnelly, 2013) but there is a clear need to better understand the interactions involved between teacher, student and technology and how these can support classroom learning.

In the effective use of digital technology, technological functions and pedagogy are bound together (Fullan & Donnelly, 2013; Mishra & Koehler, 2006). Digital technology provides tools, that may enable or mediate learning processes, but the interactivity between teacher, student and technology is fundamental in the construction of the learning environment (Wang, 2008). The affordances of the technology as a *digital* tool are important (Beatty & Gerace, 2009) but the way in which it is used determines the function it performs and whether it becomes an effective *educational* tool in the classroom context. It is important therefore, for the purposes of our study, to observe the use of iPad technology by teachers within classrooms and consider different ways of using the digital functions available.

The role of the teacher when using technology in a classroom situation is a key consideration (Roschelle & Pea, 2002) since the approach taken by a teacher affects the educational function of the technology. In their study of a networked system DeBarger et al (2010) suggest that teachers need clear pedagogical patterns or teaching routines to effectively engage students in collaborative learning using digital technology. Although their suggestions of teaching routines are specific to the context, they indicate how learning might be enriched through a formative process informed by technology. Contrasting opinions exist, however, of whether technology transforms the teacher role into being simply a ‘guide on the side’ (Roschelle & Pea, 2002) or whether technological methods are just a supplement, rather than a replacement for teachers (Higgins, 2012). Both positions imply that adjustments to pedagogy are necessary but the extent and nature of the changes required remains unclear. Through a closer examination of the interactions of teacher, student and iPad technology, we seek to clarify some of this uncertainty and explain these contrasting views.

One of the restraining factors in the expansion of technologically-enhanced methods within education seems to be the difficulty of achieving changes in pedagogy (Fullan & Donnelly, 2013). Teachers need to implement appropriate pedagogical approaches to use technology effectively in learning processes but a focus on improving teachers’ skills with digital technology that neglects associated pedagogical implications seems unlikely to be adequate (DeBarger et al, 2010; Higgins et al, 2012). Mishra and Koehler (2006) suggest that a wide range of knowledge is required to use technology effectively, using the term technological pedagogical content knowledge (TPCK). This underpinning knowledge includes understanding the representation of concepts and pedagogy when using technology, alongside knowledge of how technology can address students’ conceptual difficulties. Our interest lies, however, in a specific classroom context, in which we would expect appropriate pedagogy to be grounded in an understanding of the subject (mathematics) and the learning processes involved. As Feldman and Capobianco (2008) suggest, in their study of technologically-enhanced formative assessment, teachers' knowledge of the hardware and software needs to be accompanied by an understanding of formative assessment and related pedgagogies. In our study, teachers are involved with researchers in lesson design and implementation, so it becomes particularly important to develop a shared understanding of the relevant pedagogies within the context of learning mathematics, in addition to technical knowledge, if effective formative processes are to be constructed.

In this study, formative assessment, as defined by Black and Wiliam (2009), is used to facilitate a close view of the interactions between teacher, technology and students within a learning process and the functions they perform. We consider formative assessment as essentially a process in which information about student knowledge is gathered, interpreted and used to modify practice. This is distinguished from summative assessment by differences in purpose and effect (Sadler, 1989). The purpose of formative assessment is to gather information on student understanding and use this to make modifications to teaching and learning activities (Black &Wiliam, 1998), within the lesson or between lessons, in a way that is beneficial to student learning. In the framework described by Wiliam and Thompson (2007), teachers, students and peers are considered as actors within the formative assessment process and specified strategies are suggested that provide a means of moving student learning forward towards desirable outcomes. In our study the iPad technology also becomes an actor within formative assessment processes. Although similar strategies to those suggested by Wiliam and Thompson (2007) are considered in the analysis, we would expect some modification of these in the light of the contribution made by the technology.

Formative assessment processes involve several stages, commencing with the gathering of information on student thinking or performance. How this information is then used is crucial to the impact on student learning. A key element is the feedback that students receive (Sadler, 1989) since this potentially bridges the gap between current and desirable levels of understanding (Hattie & Timperley, 2007). Students need to be clear about where they are and where they need to be (Black &Wiliam, 2009) with feedback that builds on existing understanding (Hattie & Timperley, 2007). Information may be gathered, processed, interpreted and used in various ways, by teachers, students and their peers to indicate the way forward but teacher-student or student-student exchanges in the form of feedback and response, should be empowering to learners. This empowerment, through processes that encourage self-reflection and adjustments to thinking, is a fundamental formative assessment strategy (Wiliam & Thompson, 2007) and feedback that generates this type of self-regulation is particularly effective (Hattie & Timperley, 2007).

The capacity of digital technology to gather and process data, on a large scale and at speed, suggests that technology may be a powerful resource to support teachers in formative assessment (Looney, 2010). Digital technology may also support and empower students in formative processes by providing feedback that students can access independently as a replacement for, or an addition to, teacher-led processes. There is, therefore, the potential for iPad technology to facilitate and enhance formative assessment processes by contributing to the construction of richer and more efficient processes, that bring benefits to student learning. How iPad technology is used within these processes, the functions performed and the interactions involved, will determine whether the potential for enhancement is achieved.

Methodology

The research reported in this paper was carried out in two stages. Six lessons were developed in collaboration with teachers, using a design research approach (Brown, 1992; Swan 2014). These lessons then provided the context in which the interactions of teacher, students and iPad technology could be observed and analysed.

In the design stage, small groups of three mathematics teachers, from two different secondary comprehensive schools in the Midlands (England), worked with the authors to develop and trial the lessons. These school-based trios involved five male teachers and one female. A range of experience was represented, including one teacher in each group who had taught for less than two years. The schools were located in different urban areas but had achieved above average grading from their recent external school inspections and were of comparable size (1000-1200 pupils). Student cohorts had similar characteristics, with a lower than average proportion on free school meals. These schools were selected for the study because, despite contextual similarities, they had contrasting systems to support the use of iPads. One school issued iPads to all students from Year 10 (age 14 years) onwards for use across the curriculum. The other had class sets of iPads available through a booking system. Variations in the implementation of the lessons under such different conditions were of interest, although they are not the main focus of this paper.

During the design research, a cyclical process of design, testing, feedback, reflection and redesign (Swan 2015) was used but the aim was to explore different ways of utilizing iPad technology in formative assessment, using software familiar to the teachers (e.g. Nearpod, Showbie, Mathspace) rather than to produce a set of exemplar tasks. The design experiment was, therefore, a fusion of research and practice, as suggested by Burkhardt and Schoenfeld (2003), but with the intended outcome of understanding the interactions of technology, teacher and students in formative assessment processes rather than refinement of the actual product.

The teachers took the role of partners, contributing substantially to lesson design, implementation and review. This enabled us to establish a shared understanding of the research aims for the lessons, including how technology and formative assessment would be integrated. It also ensured that we were working with iPad technology that was familiar and accessible to the teachers so we could focus on pedagogical rather than technical issues. The design cycle was repeated three times for each lesson and in each cycle a different teacher taught the lesson to one of their classes. The first cycle for each lesson took place over a period of several weeks leading up to the first classroom implementation but subsequent iterations of the same lesson were then completed with one week. This allowed us to explore some planned and unplanned variations in how the iPad technology was used within similar lessons by different teachers.

Paired lesson observations were carried out, mainly by the two authors, but on occasions supported by other research colleagues. One of the three classroom enactments of each lesson was video-recorded for more detailed analysis. Individual interviews with the participating teachers were carried out, audio-recorded and transcribed. Additional data was also obtained in the form of meetings notes and transcripts of audio-recorded student focus group discussions.

Data analysis focused on the formative assessment processes with coding and categorization carried out in two ways. Firstly, examples of formative assessment were identified for each of the categories below. These categories, derived from previous research (Swan & Burkhardt, 2014), are based on Black and Wiliam's (2007) strategies and represent key areas of classroom activity where formative assessment may take place:

- Building on students' prior knowledge
- Identifying and responding to students' conceptual difficulties
- Using questioning
- Increasing student collaboration
- Enabling students to become assessors.

The examples were then examined for evidence of how the technology was actually used in formative assessment processes, the functions performed and the possible advantages or disadvantages for teachers.

Secondly, formative assessment processes were compared to the framework developed by Wiliam and Thompson (2007) to examine the interactions and strategies being employed (clarifying learning intentions and criteria for success; engineering effective classroom discussions to elicit evidence of student understanding; providing feedback that moves learners forward; understanding learning intentions and criteria for success; activating students as instructional resources for one another). The processes were mapped out diagrammatically (as shown in the following section) to show the interactions between teachers, iPad technology, students and peers. This then facilitated further, more detailed, analysis of the interconnected functions performed by the actors.

Results and analysis

In the first stage of analysis, examples of the use of technology in formative assessment processes were identified for each of the following five categories as follows:

1. **Building on students' prior knowledge:** Pre-lesson diagnostic assessment and class overviews are generated electronically and used in lesson planning.
2. **Identifying and responding to students' conceptual difficulties:** Sample student work is selected and displayed electronically by teachers to initiate class discussion and expose misconceptions.
3. **Using questioning:** Student work is displayed electronically by the teacher and students are questioned about their methods.
4. **Increasing student collaboration:** Students compare and discuss their work when displayed electronically for class discussion and also when working on individual iPads.
5. **Enabling students to become assessors:** Peer assessment takes place during class discussion and collaborative work using information provided electronically.

These examples were then examined in more detail to analyse how the technology had contributed to a formative assessment process. A summary for a specific example within category 1 is provided in the table below.

Summary of use	Examples of apps, systems.	Process	Assessment and response	Comparison to paper-based process
Closed response questions are sent to students to complete individually and return to the teacher. **These may or may not be processed into summaries by the system.**	For communication: Nearpod Showbie + for question design: Socrative Mathspace	Teacher gains an overview of students' facility with the content prior to lesson.	Teacher gains some information on student understanding to use in planning the lesson. Teacher may group students according to results, for example, so that one can help another.	**Advantages:** Replacement with benefit of easy access for the teacher. Summary information has benefit of the speed at which this is available to the teacher and time saved for teacher. **Drawbacks:** Limited number of question formats available on some software.

Table 1: Example of using iPads for the purpose of building on students' prior knowledge through pre-lesson diagnostic assessment.

In this particular example, small chunks of knowledge are being assessed in a formal manner by the teacher and the iPad technology provides a means of communication between teacher and student. The technology might also process the students' responses by marking these and providing a class summary.

Further examination of examples for all the five categories show how formative assessment also takes place using informal methods, such as peer to peer feedback during paired discussion, and over different time periods, which vary from a few seconds for a simple question and response, up to 30 minutes for a more extended activity. These processes are often interlinked and sometimes enacted concurrently in a 'nested' manner within overlapping time periods. The example below shows how a student-initiated formative assessment process of discussion, peer assessment and self-reflection may take place within a more extended teacher-led process of question, response, display and discussion, with both leading to adjustments to students' thinking.

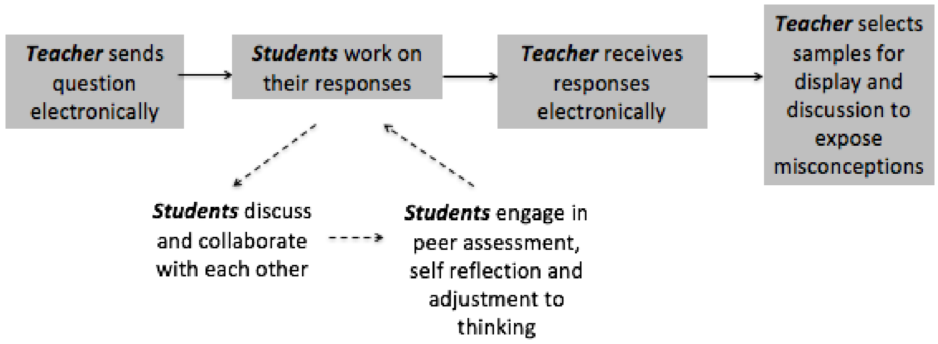

Diagram 1: Nested formative processes

The main types of formative assessment process evidenced in the study were then examined and represented diagrammatically, using three broad horizontal strata to show the contributions of the actors: teachers, students and technology. Within these diagrams, formative assessment processes are represented as horizontal progressions through four stages, which were identified from our analysis:

ASK. A question is posed (by teacher, by peers or technologically generated) that prompts the student to commence mathematical work.
ANSWER. The student provides a full or partial answer, which may be obtained from teacher observation of work in progress.
ANALYSE. An analysis of full or partial student responses is carried out by teacher, peers or technology. This may involve summarizing and interpretation but leads to feedback to either the teacher, the student or both.
ADAPT. The information received results in some adjustment to teaching and learning. This may cause re-thinking (student), changes to the lesson plan (teacher) or a change in the resources (adaptive technology).

In the following diagrams, (Diagrams 2, 3, 4 and 5) the actions of teacher, technology and students are connected by the main lines of communication between the actors. Diagram 2 brings together *some* of the formative assessment processes evidenced in the study into one representation. This is not intended to include *all* the possible processes but shows possible contributions and interactions of teachers, students, peers and technology. Three specific examples are then described and represented on Diagrams 3, 4 and 5.

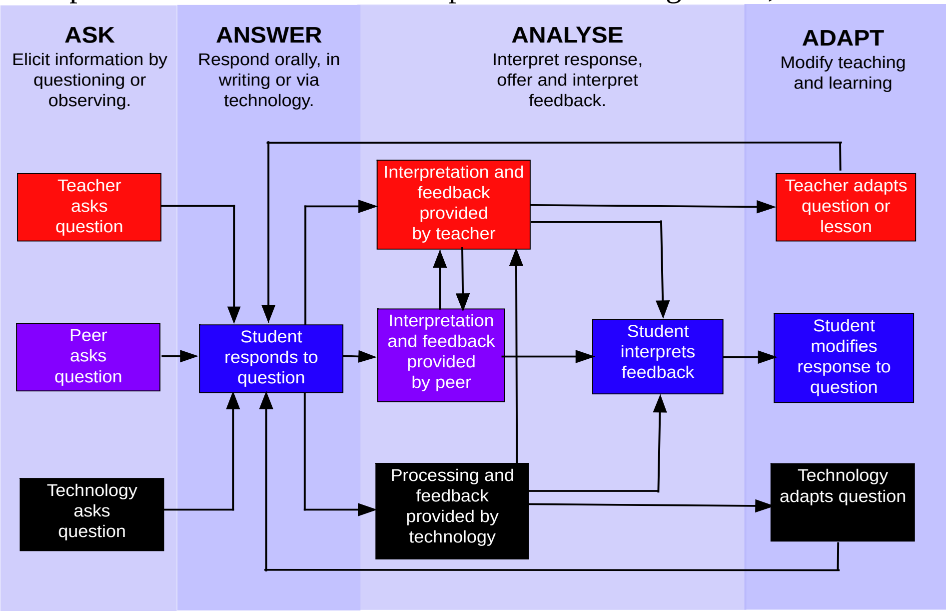

Diagram 2: A collection of stratified formative assessment processes

Example 1: The teacher sends a question to the students electronically. The students work individually on solutions using their iPads and record their methods. The students then compare and discuss solutions with each other, receiving feedback on their solutions from their peers. Students interpret the feedback, adjust their thinking and produce improved solutions.

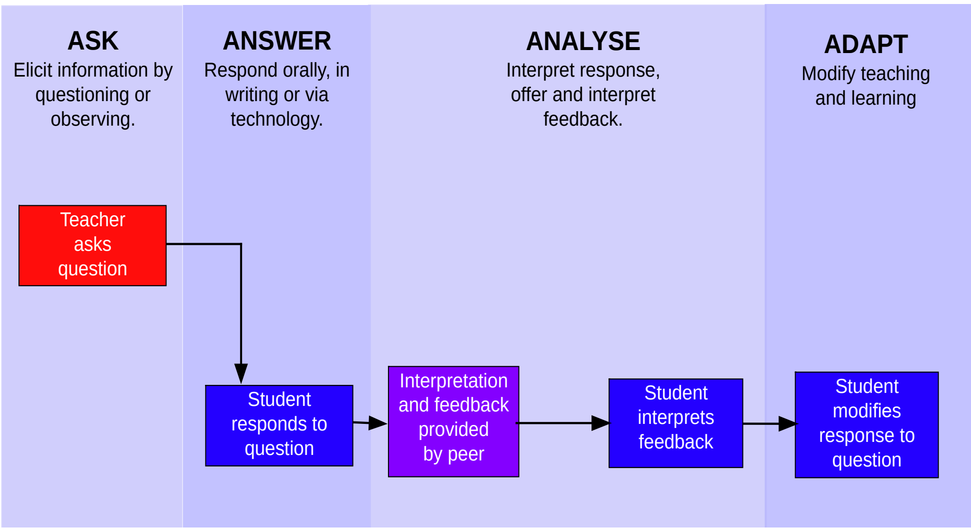

Diagram 3(Example 1): A teacher-led process with peer feedback

Example 2: The teacher poses a question verbally and also displays it on an interactive white board. The students work individually on their iPads and send their solutions electronically to the teacher. The teacher displays a sample student response, asks the class to comment and the student's peers provide feedback. The student interprets this and is challenged to rethink their solution.

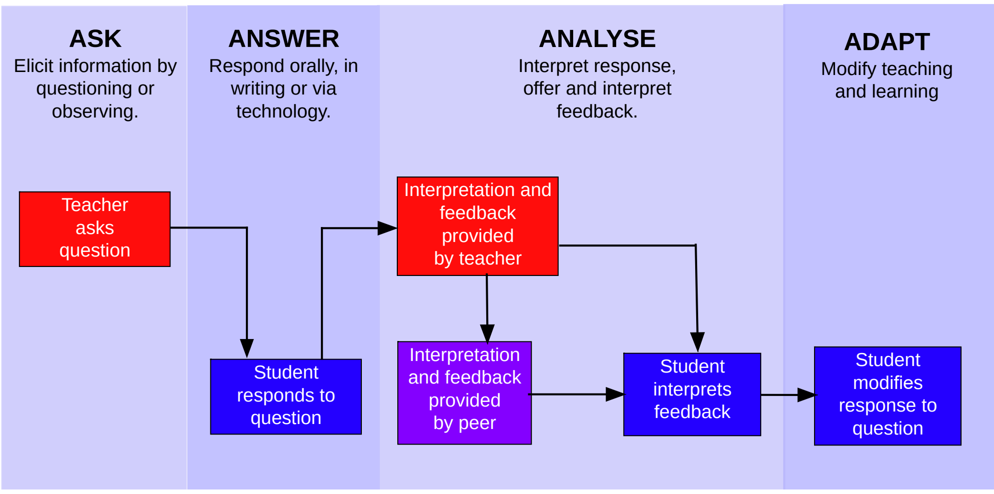

Diagram 4 (Example 2): A teacher led process with teacher and peer feedback

Example 3: The technology generates a series of questions and students respond individually, recording their responses. The technology gives feedback to the student at intervals, and adapts the next question, making it easier or harder depending on the response elicited. It also processes each response and sends back a cumulative summary to the teacher that they can access at any time to track individual or class progress. For students in difficulty, the teacher intervenes and gives additional feedback.

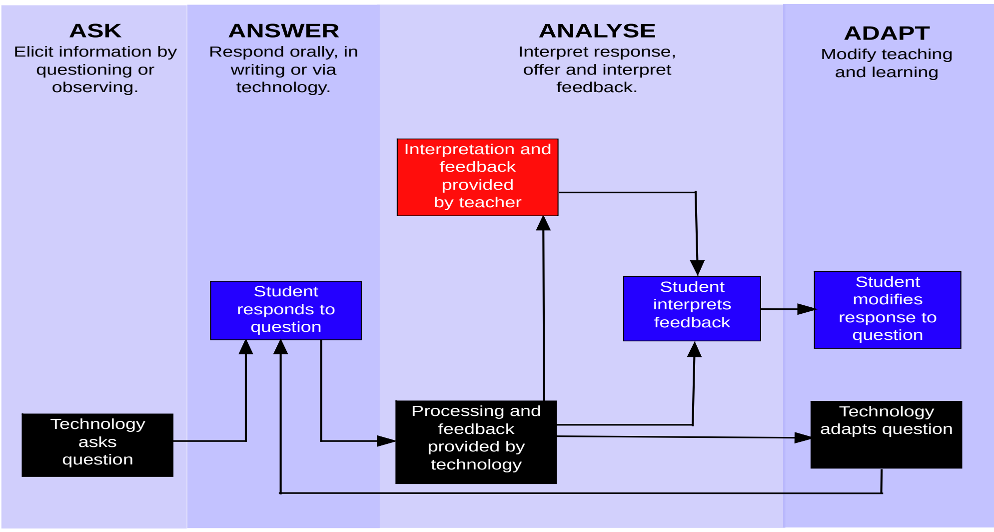

Diagram 5 (Example 3): A technology led process with feedback from technology and teacher.

Although the elements of the process are presented sequentially, the diagrams do not incorporate a time scale because this will vary between the different pathways. Formative assessment processes may involve only a short series of steps before an adapation is made and learning takes place but in other cases there may be multiple cycles of the 'asking, answering and analysing' phases before any adaptation.

Within these diagrams we can identify various functions of the iPad technology which can be generalised as either an *action* or as a means of *communication*. In each of the examples we see a series of actions and communications that involve students and teachers, and sometimes their peers, in a linked process but there is a variable dependency on the iPad technology. In Examples 1 and 2 the main contribution of the iPad technology is to provide communication between teacher and students. Consequently there is a reliance on teacher-initiated actions to progress the formative processes and these actions, in response to the data provided by the technology, constitute some of the key elements. The connection and synergy between actions carried out by the technology and the teacher are highly influential over the direction and outcome of the whole formative process.

In Example 2 (*Diagram 4)* the technology provides an overview of the class performance with a particular question (or series of questions) for the teacher. The teacher interprets this data and the progression of the formative process again largely depends on their response. In this study, teachers often used such data to make an assessment of the common misconceptions evidenced by students' responses and then provided feedback but this was carried out in different ways. More detailed analysis of the approaches used by different teachers at this point shows that gains in student understanding are highly influenced by the nature of the feedback they provide after determining the misconceptions, as Hattie and Timperley (2004) suggest.

In contrast, Example 3 (Diagram 5), shows the technology taking a more active role in the process by providing more feedback directly to the student and making an adaptation to the following question so that this is better suited to the student's learning needs. The main interactions here are between the student and the technology, with the technology contributing to both the initiation and execution of formative processes without teacher intervention. As a result, the teacher's role shifts away from being a key decision-maker towards monitoring and supporting student learning.

By using the analytic approach described here, in Examples 1 and 2, key points of interaction between teacher and technology are exposed where a teacher's pedagogical decisions direct and shape the formative process, thereby determining the effect on student learning. These decisions determine whether assessment processes are used formatively and whether additional 'nested' student-focused formative assessment loops are introduced within the broad teacher-led processes. Such 'nested' loops enrich opportunities for formative strategies (such as peer assessment and self-reflection) and can provide powerful supplements to the teacher-led processes. It is not, therefore, simply the affordance of the actual technology that is important but the teacher's responses and the type of feedback they provide.

In Example 3 we see how more sophisticated software, that incorporates feedback and adaptive questioning, alters the focus of teacher-student-technology interactions, making the contribution of the iPad technology more significant, changing the role of the teacher and empowering students in the formative assessment processes involved. The design of the software in this example is crucial to the effectiveness of these formative assessment processes, particularly with respect to the type and quality of feedback it provides.

Discussion

The results of the study show how iPad technology in these lessons performs functions that can be generalised as either a form of *communication* or a defined *action*. In agreement with Looney's (2010) suggestions, we find that functions such as rapid assessment, timely feedback, and tracking of student learning can usefully contribute to formative assessment. Within our designed lessons, we would also identify additional functions of benefit, including the accessibility of summaries of student responses for teachers, from which they can quickly identify common misconceptions, and the direct formative feedback to students provided by some interactive, adaptive software.

The actual contribution of iPad technology to formative assessment, however, varies depending on both the affordances of the *digital* tool and the way in which this is used by the teacher as an *educational* tool. Our examples show that the capacity of the software to provide formative feedback and be adaptative to students' responses, greatly influences how significantly the iPad technology contributes to formative processes. Simple response systems, can provide benefits in the speed of assessment and feedback (Looney, 2010) but this does not necessarily lead to effective formative assessment, since the quality of feedback remains important (Hattie &Timperley, 2007; Sadler, 1998), whether provided directly or mediated by the teacher. In many of our examples, the formative processes are still predominantly teacher-led and there are likely to be varied outcomes, depending on how teachers respond to the data provided and the quality of their feedback to students. For more sophisticated software, the quality of feedback provided by the technology becomes, arguably, even more important, since effective formative assessment in this case is more reliant on technologically-generated feedback than teacher intervention.

With respect to the distribution of formative assessment across the different actors (teacher, student, technology), the diagrams illustrate some of the different ways in which this was enacted. Our findings support the view that the actions of the teacher and the functions of the technology are closely bound together when using technology in the classroom (Fullan &Donnelly, 2013; Mishra & Koehler, 2006; Wang, 2008) but suggest that this mainly happens in cases where the technology is carrying out fairly simple functions of communication, marking and summarising students' responses. With more sophisticated interactive response systems, where the technology provides formative feedback and adaptive questioning, the dominant interactions are between technology and student. These differences in patterns of interaction shape the roles of teacher, technology and student in formative assessment processes and explain how differing views of the role of the teacher when using technology in the classroom might arise. In the lessons examined here, the teacher remains central when using software that only provides simple feedback to the students (such as whether their answers were correct or incorrect). With more sophisticated interactive systems that provide detailed feedback designed to prompt student thinking, the role of the teacher shifts towards being the 'guide on the side' (Roschelle &Pea, 2002).

Rather than indicating the need for clear teaching routines (DeBarger et al, 2010), the uses of iPad technology in Examples 1 and 2 suggest that there are key points in these formative assessment processes where appropriate teacher decisions can enhance opportunities for feedback and student learning. Pedagogical decisions at these points need to be informed by appropriate knowledge of how to construct effective formative assessment processes, as suggested by Feldman and Capobianco (2008). For example, teachers in our study explained how they found it necessary to develop their skills in questioning and providing verbal feedback during class discussions, in order to respond appropriately at key points and construct effective formative processes. Their views were supported by lesson observations where, in the three iterations of similar lessons by different teachers, small changes in the type of verbal questioning or feedback used by the teacher could affect how readily students gained understanding. In these examples of using iPad technology (Examples 1 and 2), the educational function of the technology is still largely within the control of teachers and, in agreement with suggestions from existing research, this accounts for some of the variations in effect (Higgins et al, 2012; Fullan &Donnelly, 2013).

In our third example, however, the technology provides additional functions, which contribute more substantially to formative assessment processes and the role of the teacher becomes less central. The pertinent question for teachers regarding pedagogical change in this case seems to be about how they can provide effective support and timely interventions. An appropriate pedagogical approach from teachers might allow the student-technology interaction to be unhindered when it is working well but to offer an alternative approach when the process is unproductive. This requires a different set of skills to the teacher-controlled use of technology in the previous examples. Although this study only focusses on a limited range of technological functions, the findings support the view that pedagogical change is needed (Fullan &Donnelly, 2013) but suggest that the adaptations required for some uses of iPad technology may be less radical than others suggest (Mishra &Koehler, 2006; Angeli &Valanides, 2009). For example, in Example 1 some technical knowledge is clearly necessary but teachers' abilities to construct formative assessment processes and identify the functions they want the technology to fulfil are fundamental (DeBarger et al., 2010). The additional pedagogical knowledge required here involves an understanding of formative assessment and the application of this knowledge, in accordance with Feldman and Capobianco's research (2008), rather than extensive technical pedagogical content knowledge, as described by Mishra and Koehler (2006). Example 3 however involves more significant changes to the teacher's role and the type of pedagogical knowledge needed for this adaptation might be more concerned with understanding how best to support students as they engage with technologically driven processes. All three examples of the use of iPad technology require pedagogical changes from teachers but the functions of the technology largely determine the type and severity of these changes.

Conclusions

In a situation where the use of technology in the classroom is still less widespread and developed than many would expect (Fullan & Donnelly, 2013; Livingstone, 2012; OECD, 2008) this study suggests that the greatest challenge for teachers in using technology in the classroom is not the technology but an understanding of the process by which it can enhance student learning. The approach taken, of analysing and visually representing technologically-assisted processes, highlights how teachers are often essential to the construction of effective formative processes, although their role can also become more peripheral when the technology has the capacity to perform more powerful functions.

Rather than indicating the need for a radical new pedagogy (Livingstone, 2012), the findings suggest that many existing pedagogies can be harnessed and used effectively when using iPad technology in a classroom situation. This conclusion arises from a small focused study and does therefore not exclude the possibility that new pedagogies may be required to effectively utilize technology when it performs different functions. Issues associated with the possible transformation of mathematical concepts through technology, for example, are beyond the scope of this study. The research does, however, provide valuable insight into how simple uses of iPad technology in mathematics classrooms can enhance student learning through the construction of rich formative assessment processes.

This study offers an analysis of how technology may be used effectively in ways that are currently available in many classrooms. The use of formative assessment and the visual representation of the processes involved provides a means of assessing the contribution of iPad technology to student learning and understanding the interactions of teacher, technology and student that are involved. We suggest that this analytic approach has value, both for further research into the effects of technology on student learning and as a guide to assist teachers when planning how to use technology in ways that will be of benefit to student learning.

Acknowledgements

This research project has received funding from the European Union's Seventh Framework Programme under grant agreement no 612337.

Statements on open data, ethics and conflict of interest

The data can only be accessed in an anonymized form.

Ethical approval for this research was gained from the University of Nottingham, School of Education ethics committee in accordance with the university and BERA guidelines.

There are no conflicts of interest for the authors.

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