Executive Summary

FaSMEd was a collaborative development project, which adapted the principles of design research (Swan, 2014) in its methodology. A consortium of international partners researched the role of technologically enhanced Formative Assessment (FA) methods with the view to developing a toolkit that would inform teachers of emergent FA pedagogies in mathematics and science education.

Through intervention cases in science and/or mathematics in each of the partner countries, innovative technology was introduced to create a digital environment which enhanced connectivity and feedback to assist teachers in making more timely formative interpretations. The FaSMEd project explored the potential to amplify the quality of the evidence about student achievement both in real-time and outside the classroom for access by both students and teachers.

The FaSMEd project found that the introduction of innovative technology to create a digital environment (between students, peers and teachers) can assist teachers in making more timely formative interpretations. We recommend the use of such technologies within classrooms to further enhance FA practices.

Through the case studies there is evidence of teachers using technologies to gain information about their students' thinking, as well as to facilitate opportunities for students to learn from their peers. In interviews, students identified these practices as particularly beneficial in making their learning visible to the teacher, themselves and their peers. We recommend that technologies are utilised within classrooms to facilitate making learning more visible to all 'in the moment'.

Our FaSMEd case studies show that most teachers opted for technology tools which were accessible and/or easy to learn how to use and apply in their classrooms. We recommend that when embarking on new technological innovations, the usability of tools is considered.

FaSMEd found that where existing infrastructures supported the use of technology, schools were able to make considerable progress in their use of technology to support FA practices. We would recommend investment in the networking and wireless systems, together with technical support in schools. FaSMEd believes this is a priority and a pre-requisite for the implementation of this technology on a larger scale.

Where teachers were able to work as professional learning communities, conditions were effective in enabling them to feel safe to experiment, examine the impact of their innovations, to talk openly and to establish principles about effective student learning. FaSMEd would therefore recommend that schools (wherever possible) facilitate time and space for teachers to plan, and reflect on their practice. A commitment to this from school leaders is crucial.

The main objectives for the FaSMEd project were to produce (through design research) a FaSMEd Toolkit for teachers and teacher educators and a FaSMEd Professional Development (PD) resource. The expression 'toolkit' refers to a set of curriculum materials and methods for pedagogical intervention. These were designed to support the development of practice and are disseminated through a website produced by the partners, and can be accessed at: http://fasmed.eu.

Introduction

The Rocard report (2007) identified widespread concern across the EU about the economic consequences and social impact of underachievement in mathematics and science education and recommended the adoption of an inquiry based pedagogy. As a consequence, a range of research projects were commissioned by the EC, for example: SAILS – Strategies for Assessment of Inquiry Learning in Science; MASCIL – Mathematics and Science for Life; PRIMAS – Promoting Inquiry in Mathematics and Science Education across Europe, and ASSIST-ME - Assess Inquiry in Science, Technology and Mathematics Education. FaSMEd – Formative Assessment in Science and Mathematics Education was the final project commissioned in the FP7 programme, with a specific remit to explore the application of technology to facilitate FA in the classroom.

FaSMEd was a collaborative development project, which has adapted the principles of design research (Swan, 2014; Burkhardt and Schoenfeld, 2003) into its methodology. This is a formative approach in which a product or process (or 'tool') is envisaged, designed, developed and refined through cycles of enactment, observation, analysis and redesign (Gravemeijer and Cobb, 2006), with trials in 'real' situations (Collins et al., 2004) and systematic feedback from end-users. Educational theory is used to inform the design and refinement of the tools, and is itself refined during the research process. Its goals are to create innovative tools for others to use, to describe and explain how these tools function, account for the range of implementations that occur and develop principles and theories that may guide future designs. Ultimately, the goal is transformative; we seek to create new teaching and learning possibilities and study their impact on end-users.

A key element of teaching using assessment and intervention relates to the quality of the information generated by the various feedback loops that exist in the classroom setting and the involvement of the students within this process. Through intervention cases in science and/or mathematics in each of the partner countries, innovative technology was introduced to create a digital environment which enhanced connectivity and feedback to assist teachers in making more timely formative interpretations. The FaSMEd project explored the potential to amplify the quality of the evidence about student achievement both in real-time and outside the classroom for access by both students and teachers.

The main objectives for the FaSMEd project were to produce (through design research) a Toolkit for teachers and teacher educators (Deliverable D3.3) and a Professional Development (PD) resource (Deliverable D3.6). The expression 'toolkit' refers to a set of curriculum materials and methods for pedagogical intervention. These were designed to support the development of practice and are disseminated through a website produced by the partners, and can be accessed at: http://fasmed.eu.

The Professional Development (PD) package produced by FaSMEd reflects the range of ways in which partners have worked with teachers in their countries and offers examples for teachers and teacher educators to use. These include a set of six PD modules designed to help teachers use FA and technology more effectively in their classrooms. The resources also include a theoretical section on principles for effective professional development and a practical section on ways in which professional development can be organised. This section is meant to be used by people who are organising professional development for teachers of mathematics and science but can also be used by teachers either individually or working with peers.

The FaSMEd Project in action

At the start of the project work package 1 laid the theoretical and methodological base for the historical and current assessments and the intervention cases that were to follow in the partner countries. In work package 2 the objective was *the establishment of a baseline of data on the approaches to low achievers in mathematics and science across the EU and South Africa*. The successful completion of this work package offered an overall view on the existing approaches to low achievers in the participating countries and across the EU and SA. Moreover, it enabled us to identify the range of tools and technology available to support teaching and assessment in mathematics and science. These results were informative with respect to the development of the toolkit in work package 3 which ran throughout: *design, evaluation and further development of the toolkit and professional development package*. Within work package 4, all partners had a cluster of schools to implement the FA approaches in sciences and/or mathematics. This was the focus for intervention with teachers and students to implement FaSMEd activities developed in WP3. Each partner team worked with between two to four intervention cases in mathematics and/or science education, and amongst those there was at least one case on the content of "graphs/functions".

The FaSMEd project was based on the evidence (Black & Wiliam, 1998) that FA strategies can raise levels of achievement for students. The project also builds on the evidence of research from, for example, the LAMP (Ahmed, 1987), RAMP (Ahmed & Williams, 1991) and IAMP (Watson, De Geest, & Prestage, 2003) projects in mathematics teaching and the CASE (Shayer & Adey, 2002) project in science teaching in the UK and elsewhere which adopted approaches focused on the proficiencies of the students rather than their deficiencies. These projects adopt what Shulman (2002) calls 'pedagogies of engagement', characterised by: revisiting student thinking, addressing conceptual understanding, examining a task from different perspectives, critiquing approaches, making connections and engaging the whole class.

Partners were encouraged to identify activities in science and mathematics which built on recent meta-analyses of the accumulated corpus of research on effective teaching that have examined teaching components in mathematics and science (Seidel & Shavelson, 2007), teaching strategies in science (Schroeder, Scott, Tolson, Huang, & Lee, 2007), and teaching programmes in mathematics (Slavin & Lake, 2008; Slavin, Lake, & Groff, 2009). These provide clear indications of the relative effectiveness of some types of teaching component for lower achievers.

During the first year of the project, time was allocated to establish a common understanding of the key concepts of FaSMEd. These were articulated through a series of Position Papers (https://research.ncl.ac.uk/fasmed/positionpapers/) and an agreed Glossary (Deliverable 1.2).

We recognised that an approach to learning through active participation in, and reflection on, social practices, would be desirable. Further, FaSMEd activities should stimulate 'conflict' or 'challenge' to promote re-interpretation, reformulation and accommodation. The aim was to devolve problems to learners so that learners could articulate their own interpretations and create their own connections.

Partners were encouraged to create and adopt activities from their own contexts which reflected this approach to learning. However, since this approach increases the cognitive load for students it is important that the learning environment is engineered to support students and FaSMEd included technology as part of the design of the environment to provide such support. The FaSMEd project case studies provide examples of where this approach has worked successfully with lower achieving students.

Wiliam and Thompson (2007, adapted from Ramaprasard, 1983) focus on three central processes in teaching and learning: (a) Establishing where the learners are in their learning; (b) Establishing where the learners are going and (c) Establishing how to get there. Considering all agents within the learning processes in a classroom: teacher, students and peers, they indicate that FA can be conceptualized in five key strategies (see figure 1):

1) Clarifying/ Understanding/ Sharing learning intentions and criteria for success;
2) Engineering effective classroom discussions and other learning tasks that elicit evidence of student understanding;
3) Providing feedback that moves learners forward;
4) Activating students as instructional resources for one another;
5) Activating students as owners of their own learning.

	Where the learner is going	Where the learner is right now	How to get there
Teacher	1 Clarifying learning intentions and criteria for success	2 Engineering effective class-room discussions and other learning tasks that elicit evidence of student understanding	3 Providing feedback that moves learners forward
Peer	Understanding and sharing learning intentions and criteria for success	4 Activating students as instructional resources for one another	
Learner	Understanding learning intentions and criteria for success	5 Activating students as the owners of their own learning	

Figure 1: Key strategies of Formative Assessment (Wiliam & Thompson, 2007)

The key strategies by Wiliam and Thompson (2007) constitute the foundation of the theoretical framework that has been developed within the FaSMEd project. They represent, indeed, the starting point for the development of a three-dimensional framework (see figure 2) aimed at extending their model to include the use of technology in FA processes.

The FaSMEd framework (Figure 2) takes into account three main dimensions which enabled the project team to characterise technologically enhanced FA processes: (1) the five key strategies of FA introduced by Wiliam and Thompson (2007); (2) the three agents that intervene in the FA processes and that could activate these strategies, namely the teacher, the student and the peers; (3) the functionalities of technology.

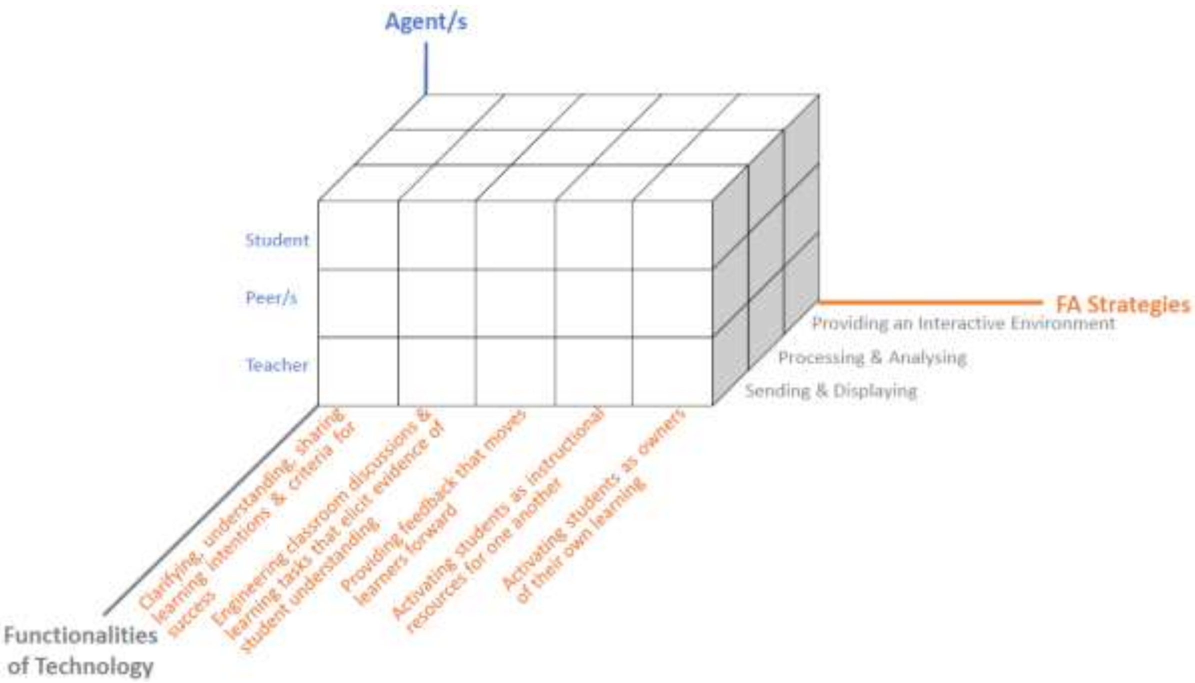


Figure 2: The FaSMEd framework

We introduced the third dimension **Functionalities of Technology** with the aim of highlighting how technology could support the three agents involved in FA processes when they activate the different FA strategies. The functionalities of technology are subdivided into three categories: sending and displaying, processing and analysing and providing an interactive environment. This subdivision was based on the FaSMEd partners' experience in the use of technology to support FA processes.

The **Sending and Displaying** category includes those functionalities of technology that support communication and fruitful discussions between the agents of FA processes. For example, the teacher sending questions to the students or displaying a student's screen to show his/her work to the whole class. Several other functionalities such as sending messages, files, answers or displaying screens or students' worksheets belong in this category.

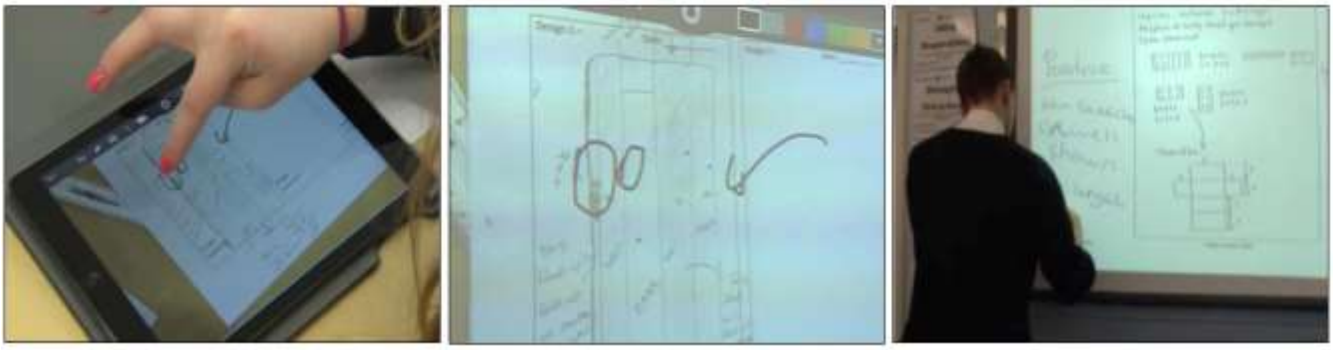
The functionalities that support the agents in the processing and analysis of the data collected during the lessons are included in the category **Processing and Analysing**. This could include a software that generates feedback based on a learner's answer or an application which creates statistical overviews of solutions of a whole class, e.g. in a diagram or table. Other examples are the generation of statistics of students' answers to polls or questionnaires as well as the tracking of students' learning paths.

The third category, **Providing an Interactive Environment**, refers to those functionalities of technology that create a shared interactive learning environment within which students can work individually or collaboratively on a task to explore mathematical/scientific concepts and processes. This category includes, for example, shared worksheets, dynamic geometry software files, graph plotting tools, spread sheets, dynamic representations or ChemSketch models.

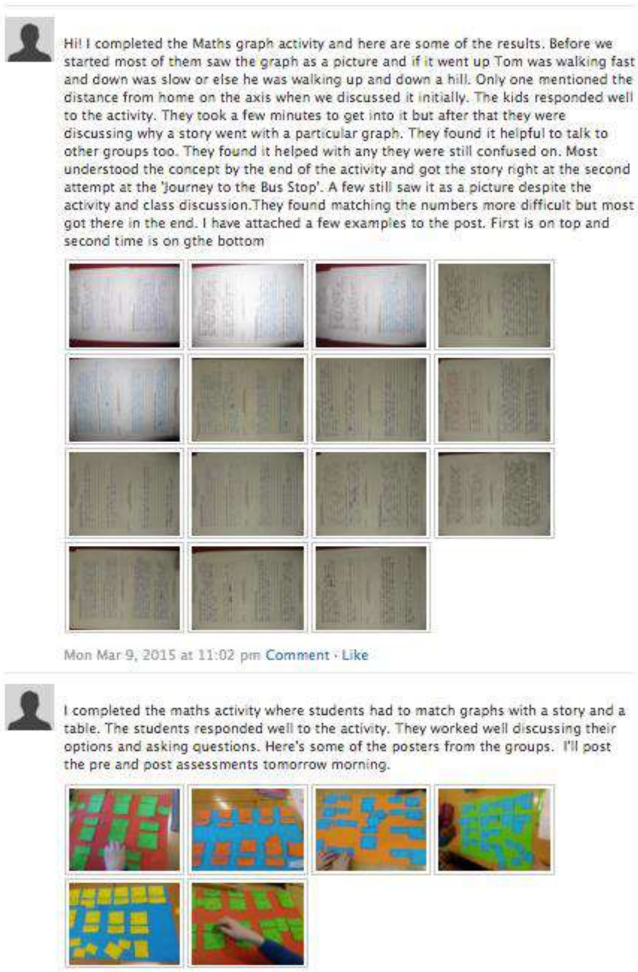
Figure 2 shows how the subdivision of each dimension into different sub-categories identifies small cuboids within the diagram. Each cuboid helps to locate specific FA practices, highlighting the agents involved in this practice, the main FA strategies that are activated and the functionalities of the technology that is involved. The framework is not hierarchical in that no section of the cube is viewed as being more or less desirable than others. The framework has been used to identify and locate each of the cases reported by the partners in the project and has been the focus of a number of published papers and presentations at international conferences.

Examples of sending and displaying in practice

One school working with Newcastle University (UK) implemented interactive whiteboards with a reflector technology into classrooms. While students worked on the activity ‘Designing Candy Cartons’ on their iPads, the technology enabled the teacher to display a student’s screen to the whole class, sharing his/her work, while making it possible to annotate and comment visibly in real time:



At the University of Maynooth (Ireland), teachers used Schoology. This is a learning management and social network system, used in classrooms as a way for teachers and students to communicate by sharing materials, learners uploading their work, teachers sending out tasks and providing a way to give feedback and ask questions:

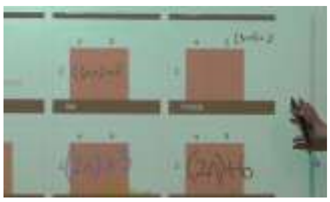


Hi! I completed the Maths graph activity and here are some of the results. Before we started most of them saw the graph as a picture and if it went up Tom was walking fast and down was slow or else he was walking up and down a hill. Only one mentioned the distance from home on the axis when we discussed it initially. The kids responded well to the activity. They took a few minutes to get into it but after that they were discussing why a story went with a particular graph. They found it helpful to talk to other groups too. They found it helped with any they were still confused on. Most understood the concept by the end of the activity and got the story right at the second attempt at the 'Journey to the Bus Stop'. A few still saw it as a picture despite the activity and class discussion.They found matching the numbers more difficult but most got there in the end. I have attached a few examples to the post. First is on top and second time is on gthe bottom

Mon Mar 9, 2015 at 11:02 pm Comment · Like

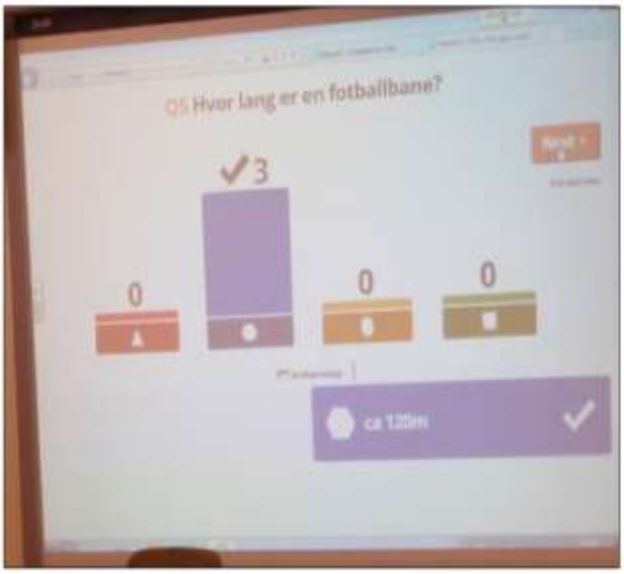
I completed the maths activity where students had to match graphs with a story and a table. The students responded well to the activity. They worked well discussing their options and asking questions. Here's some of the posters from the groups. I'll post the pre and post assessments tomorrow morning.

An example from the University of Nottingham (UK) arose during lessons in which areas of rectangles were used to explore algebraic expressions. The software *Nearpod* was used by the teacher to send questions to students to complete on their iPads. Students returned their answers using *Nearpod* and an array of student responses was then displayed for the class to compare and discuss.

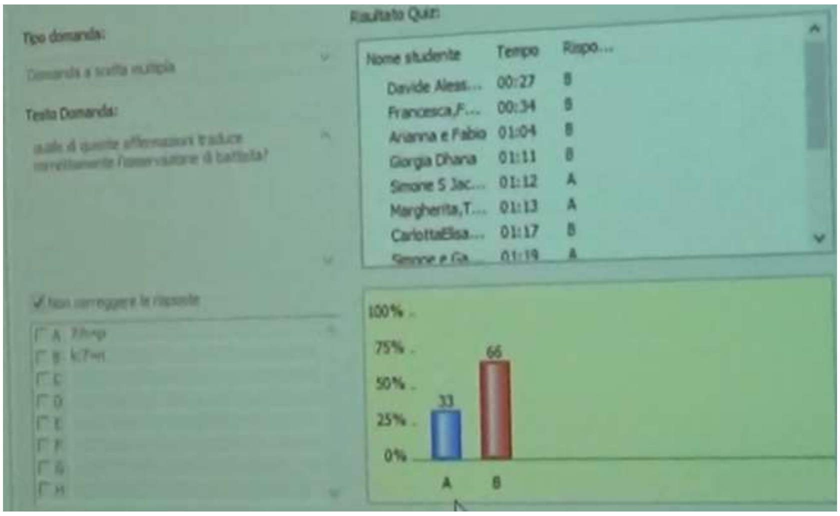


Examples of processing and analysing in practice

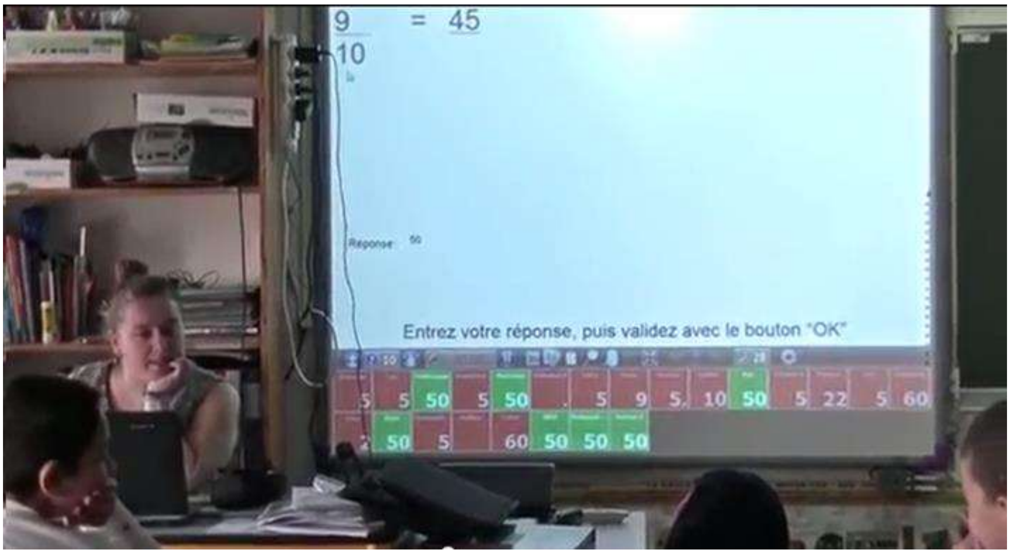
In the activity 'Unit of length' developed by the University College of Trondheim (Norway) the applet Kahoot is used for sending questions to students, sending their answers to the teacher and the teacher displaying the students' solutions to discuss and give feedback. What is more, the technology produces a statistical overview represented in a bar diagram of the whole class' answers and therefore helping students and the teacher to grasp all students' solutions at once:



Also in the teaching interventions carried out by the University of Turin (Italy) with the software IDM-TClass, results of test and polls are gathered and processed on the teacher's laptop, and shown on a wider screen by means of a data projector or an interactive whiteboard. In this case the technology collects all the students' choices and processes them, displaying an analytical record (collection of each answer) as well as a synthetic overview (bar chart). The teacher can choose to provide or not an immediate automatic feedback to students' answers (right/wrong). The Italian team's choice was to use the results provided by the software as a starting point for engineering class discussions.



Another example of this functionality is the tool 'Equivalence of fractions' developed at Ecole Normale Superieure De Lyon (France). It uses a student response system (Je leve la main) to display a question to the whole class, which each learner then answers individually via a remote control. Then, the technology analyses the answers indicating in green or red colour whether a student's solution was correct and shows what the answer of each individual student was. The teacher can finally display all the sent in solutions to discuss the problem with the whole class and give feedback:

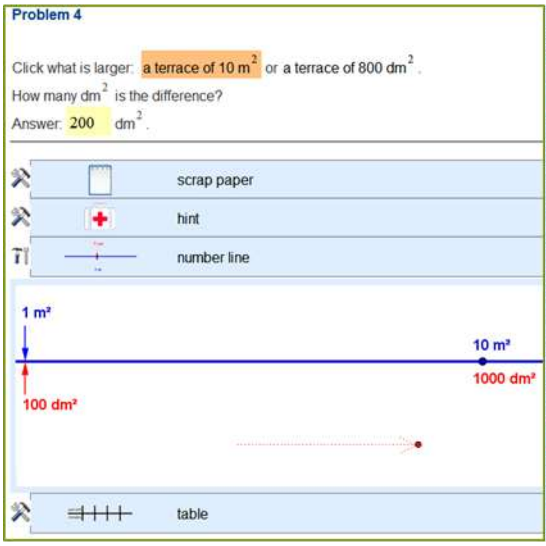


Pre-lesson assessment was carried out by one school working with the University of Nottingham (UK) using diagnosticquestions.com. Students completed multiple choice questions before the lesson and an overview was provided for the teacher so that they could adjust their lesson plan to suit the level of prior understanding of the students and address any particular misconceptions.

Examples of providing an interactive environment in practice

The digital self-assessment tool 'Can I sketch a graph based on a given situation?' developed at the University of Duisburg-Essen (Germany) functions as an interactive environment, in which students can explore the mathematical content of sketching a graph dynamically and assess their own work based on a presented check-list:

Another example of technology used for formative assessment in the functionality of 'Providing an Interactive Environment' was designed by Utrecht University. They created four different modules in an online Digital Assessment Environment (DAE), for instance one on the metric system. Within this environment, learners work on a series of questions while being able to choose between a number of different tools to help them solve a problem, like tables, scrap papers, hints, percentage bars, etc. The technology then presents an overview of the students' work, their chosen tools and answers to the teacher, who can use this data formatively:



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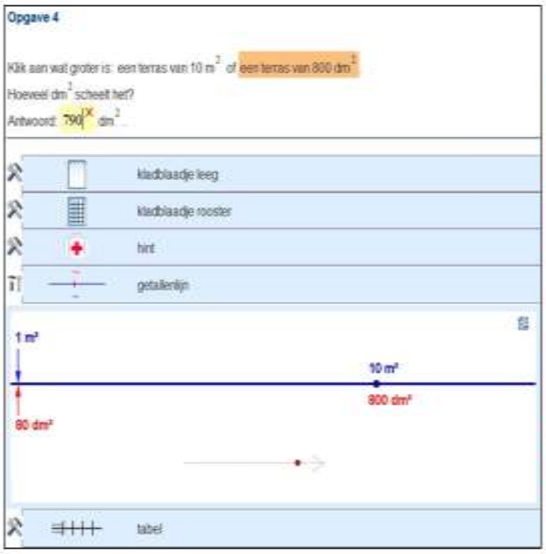
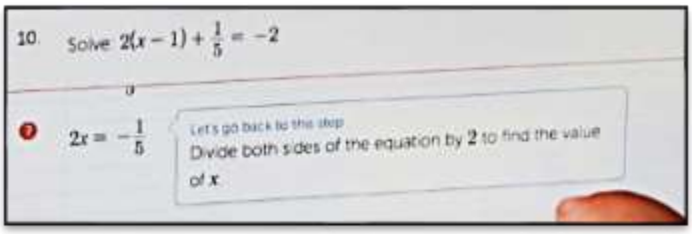


Other students in England (University of Nottingham) used existing systems such as *Mathspace* which provides questions and hints for students to help them reflect on their own learning and progress relatively independently from the teacher.



Cross-comparison of the FaSMEd cases

Our schools and teachers used very different technological tools in their mathematics and science classrooms, and worked under different conditions and environments. Hence, a true comparative analysis was not possible, as many variables change with the use of different tools, change of environment, etc. As outlined in Deliverable D5.1, our intention was not to compare teachers internationally, but rather to develop deeper insights into how FA strategies (in particular technology-based) can help teachers and students to develop better learning trajectories. The following statements summarise the main findings from the cross case study analysis (Deliverable D5.2):

Statement 1
The technology can provide immediate feedback, potentially useful for teachers and students. However, the usefulness depends to a large extent on teachers' skills to benefit from it, as they often do not know how to helpfully interpret and use the

feedback into their teaching, in particular for using it formatively to benefit pupil learning.

Statement 2
The technology potentially provides, and even seems to encourage, ample opportunities for classroom discussions. Moreover, it appears that the technology helps to develop more cooperation within the class: teacher-student cooperation; and opportunities for cooperation between individual students/within groups.

Statement 3
Technology appears to provide an 'objective' and meaningful way for representing problems and misunderstandings.

Statement 4
Technology can provide opportunities for using preferred strategies in 'new' or different ways.

Statement 5
The technology helps to raise issues with respect to FA practices (for teachers and students), which are sometimes implicit and not transparent to teachers. In nearly all the cases the connection of FA and technology tools helped teachers to re-conceptualize their teaching with respect to FA.

Statement 6
Different technological tools provide different outcomes: in principle, each tool can be used in different ways, for example, feedback to an individual; feedback to groups of students; feedback to the whole class and discussion. Often a mix of technology was used, and the orchestration of the technology tools needs particular skills.

Teachers' experiences of the design process

Through FaSMEd, consortium partners (and teachers) have engaged in the design process of socio-technical approaches aimed at raising achievement in mathematics and science education. Here we provide illustrative examples of the experiences of teachers and students using the FaSMEd activities.

Looking across the cases, it is clear that the technology tools provided immediate feedback for teachers about pupils' difficulties and/or achievement with a particular task. For example, in the case of the DAE tool being used in a mathematics lesson, it provided opportunities for collecting and processing students' summative results, and subsequently for further analysing individual student work, based on students' use of various optional auxiliary tools. As another example, a mathematics teacher mentioned that "*other effective moments are the polls, since they are immediate and interesting*".

We found that teachers see the technological tools as *opportunities* for changing practices, in the sense that teachers expanded their repertoire of strategies with the technological tools:

> *"[Before FaSMEd] the use of Formative Assessment was implicit. I had very low awareness of it. No specific tool was constructed or used for this purpose. [Now FA is] gathering information at all steps of the teaching act."*

Teachers adapted their preferred strategies in new or different ways: for example, one teacher reported that the tablet made her work more cooperatively with her class and removed her from the 'constraints' of the whiteboard:

> *"It just means that I'm not at the front all the time."*

Another teacher commented that although questioning was his predominant approach, he was aware that:

> *"not all students are comfortable to answer questions vocally or to be putting their hands up [....] sometimes you have to use other methods that are not as intrusive, things like using mini whiteboards where everyone can respond and no-one feels under pressure".*

The tool (or resource), such as a clicker or iPad, used in an applied way, becomes an instrument for a particular FA strategy as outlined in the FaSMEd framework. Within our cases, FA practices were then associated with particular functionalities of the technology tool/s: for example, with sending and displaying questions; and with displaying students' answers.

Several of our case study teachers reported that particular technical difficulties, such as setting up the technology, or handling it with students, prevented them from using the technology tools more often. However, once they managed the tools successfully, and moreover saw the advantages of using them for FA, they regarded them as beneficial both for their instruction and for student learning. One teacher suitably commented:

> *"[before FaSMEd] the collection of information was done through conventional controls, activities at the beginning of the lesson, oral exchanges, observations of students in their activities. The quality and consistency of the treatment of such information varied widely. There were some technical difficulties related to the handling of the material, during the first two months of the FaSMEd project. Today I see only advantages of using digital technologies for formative assessment.*"

Students' experiences of the design process

For students, there was an appreciation of the value of FA and that through sharing and explaining work the teacher would "*know you haven't just copied, because if you had copied then you wouldn't have been able to explain the answer*". One student did explain that it was important not to be judged or humiliated. The classroom culture created by the teacher would therefore appear to be crucial if 'in the moment' FA strategies are adopted, i.e., students need to feel it is safe to explain their ideas even if they might be wrong:

> *"If you're in class and you're doing a question on the tablet, if you get something wrong it's easier to tell than just writing it in your copy where you only can see, then the whole class can see and tell you where you went wrong."*

Students thought that the technology also helped teachers to get a better (i.e. objective and observable) overview of how students were progressing:

> *"well, [teachers] can see what we've done better, it's hard to explain, if we do stuff on technology they can save it … they can see it … it's hard for them to know how we're getting on…"*

Representing their knowledge in a meaningful way was perceived to be especially beneficial to lower achieving students, as it allowed them to represent their learning pictorially. Students could make sense of images and videos within a particular application (e.g. iPad application Popplet).

Some students reported that working with these technology tools helped them to improve their learning, and facilitated their understanding of mistakes. It was reported that after FaSMEd, students changed their minds on the utility of using clickers in maths and science lessons, in particular for using the projected answers for discussions with respect to their own results/answers. Selected students reconsidered the status of mistakes for their learning, they realised that mistakes could be useful in the learning process:

> *"You made a mistake, that's all, but [now] you know that you have understood."*

Nearly all the case studies reported on the positive effect of technology in terms of facilitating and encouraging classroom discussions, either between teacher and students, or amongst students. Many students appeared to have had ample opportunities for peer interactions, partly due to the technology, in terms of: paired discussions; students compared samples displayed, interpretations and strategies from peers, suggestions from peers, solutions, working and explanations from peers.

All the case studies reported an impact on student motivation and engagement. One teacher reported:

> *"I feel that my students are more confident in approaching unfamiliar tasks. They are more likely to 'have a go' at a task. The need to share work with their partner and to improve their own work, has helped them to appreciate the need to get something down on paper and to try things out. It has also helped their accountability in needing to complete a task, rather than just saying say 'I don't know what to do'."*

In some cases, teachers reported increased engagement and an improvement in the quality of student work due to the key role that technology played in displaying their work to their peers:

> *"If they know that they are going to have to present their work to the rest of the class they make much more effort with it".*

In other words, it was not the technology itself, but the knowledge that the technology *could* be used which had an impact on the quality of some students' work.

Disseminating the outcomes of FaSMEd

The FaSMEd Toolkit

The main objectives for the FaSMEd project were to produce (through design research) a Toolkit for teachers and teacher educators (Deliverable D3.3) and a Professional Development (PD) resource (Deliverable D3.6). The expression 'toolkit' refers to a set of curriculum materials and methods for pedagogical intervention. These were designed to support the development of practice and are disseminated through a website produced by the partners, and can be accessed at: http://fasmed.eu.

Professional Development package

The Professional Development (PD) package produced by FaSMEd reflects the range of ways in which partners have worked with teachers in their countries and offers examples for teachers and teacher educators to use. These include a set of six PD modules designed to help teachers use FA and technology more effectively in their classrooms. The resources also include a theoretical section on principles for effective professional development and a practical section on ways in which professional development can be organised. This section is meant to be used by people who are organising professional development for teachers of mathematics and science but can also be used by teachers either individually or working with peers.

The FaSMEd position paper on Professional Learning of teachers warned that Professional Development (PD) is perceived and experienced differently across countries. Partners were aware, therefore, that it was important not to assume too much about expectations and norms in other countries. However, the position paper then goes on to conclude that there is a high degree of convergence in descriptions of successful professional learning and the partners generally agreed. Typically, these include securing interest and engagement from the teachers, providing a theoretical framework for understanding of the innovation/strategy/programme and offering some practical tools to apply to classroom practice (Timperley et al., 2008).

The position paper also notes that *Professional Learning Communities* (PLC) (Wenger, 1998) emerge as one of the most promising structures for professional learning, particularly when these involve collaborative inquiry (e.g. OECD, 2013; Ermeling, 2010; Nelson et al., 2008). This is because the conditions for effective professional learning, fundamentally require teachers to feel safe to experiment, examine the impact of their innovations, to talk openly and to establish principles about effective student learning (Joubert & Sutherland, 2008). Partners were thus encouraged to engage with groups of teachers who were willing to collaborate as active participants in the design process of the resources for the toolkit and to support PLC's where possible.

In FaSMEd all partners used an *active* involvement of the teachers in the design-based research process as professional development. Teachers were involved through cluster meetings and school visits throughout the intervention phase of the project (2014/2015). These meetings included dialogues with the FaSMEd researchers, sharing of practice with other teachers as well as participating in the 'design-do-review cycles' of classroom materials. However, the organisation of this approach was very different for each FaSMEd partner but essentially fell into three main types: courses; learning groups and individual teachers.

FaSMEd findings: What makes a difference?

Technology facilitating Formative Assessment

FaSMEd researchers reasoned that a key element of teaching using FA and intervention relates to the quality of the information generated by the various feedback loops that exist in the classroom setting and the involvement of the students within this process. The introduction of innovative technology to create a digital environment which enhances connectivity and feedback between students, peers and teachers can assist teachers in making more timely formative interpretations. This further has the potential to amplify the quality of the evidence about student achievement, both in real-time and outside the classroom, for access by both students and teachers.

Through the case studies there is evidence of teachers using technologies to gain information about their students' thinking, as well as to facilitate opportunities for students to learn from their peers. In the FaSMEd Framework this represents providing feedback that moves learners forward by means of the *Sending and Displaying* functionality of technology, as well as potentially *Activating Students as Instructional Resources* for one another and, as a result of the activation of these strategies*, Activating students as owners of their own learning*. In interviews, students identified these practices as particularly beneficial in making their learning visible to the teacher, themselves and their peers.

In addressing the needs of lower achievers in particular, a number of interventions used technologies that could be more easily accessible and did not demand high levels of literacy. Using polls and/or pictorial representations were shown to be useful in some circumstances. Polls had the further advantage of *Processing and Analysing* data in real time.

Where technologies were able to *Provide an Interactive Environment*, students could access a variety of tools to scaffold their learning. This enabled lower achieving students to engage more fully in tasks and therefore A*ctivating students as owners of their own learning*. Further, at the FaSMEd Final Meeting (Deliverable D8.4), it was argued that FA practices provide a meaningful reason for using technology in the classroom. Fullan & Donnelly argue:

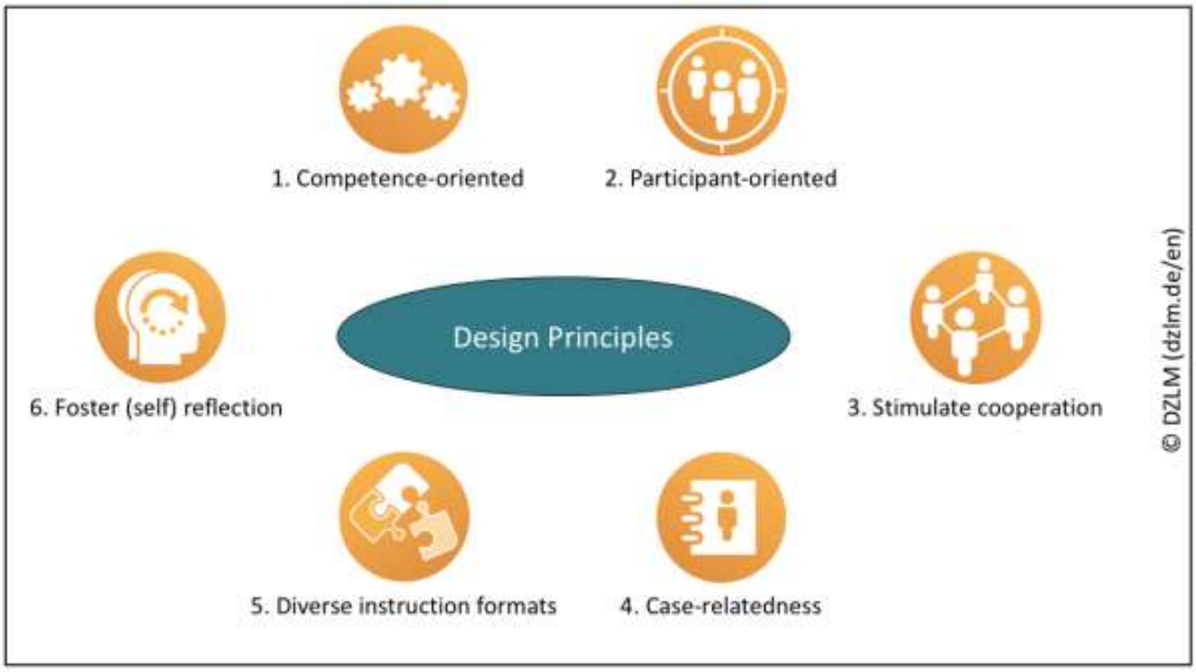
"*Up to this point, technology has not impacted schools. We agree with Diana Laurillard (2012) that technological investments have not been directed at changing the system but only as a matter of acquisitions. Billions have been invested with little thought to altering the learning* *system. There are also potentially destructive uses of technology on learning; we must beware of distractions, easy entertainment and personalisation to the point of limiting our exposure to new ideas. We focus not simply on the technology itself but on its use." (Fullan & Donnelly, 2013, p.10).*

Our case studies show that most teachers opted for technology tools which were accessible and/or easy to learn how to use and apply in their classrooms. The case studies recognised that a limiting issue for a number of teachers was the ergonomic environment which produced connection difficulties in the system, increasing the time taken for the feedback to arrive from and to the students and therefore forming a potential obstacle to the adoption of the technology. Investment in the networking and wireless systems (and technical support available) in schools would seem to be a priority and a pre-requisite for the implementation of this technology on a larger scale.

Investing in teacher learning

It has been strongly argued that in order to bring about real change within schools, investing in the building of the capacity of teachers, with teachers being the key agents of change (Fullan, 2010), should be the main emphasis of schools' policy (IPPR, 2013).

A detailed analysis of Continued Professional Development (CPD) by the DZLM (Deutsches Zentrum für Lehrerbildung Mathematik/German Centre for Mathematics Teacher Education, Barzel & Selter, 2015, p. 259–284) identifies the following design principles for effective CPD:



Principles for effective continuing professional development (CPD)

The FaSMEd case studies demonstrate how professional learning was facilitated through a number of structures: courses, direct work with individual teachers and/or teacher learning groups. These are exemplified through the Professional Development package. Our work with teachers has highlighted that where teachers were able to work as professional learning communities, conditions were effective in enabling them to feel safe to experiment, examine the impact of their innovations, to talk openly and to establish principles about effective student learning. As argued in our position paper on Professional Learning of teachers, we note that *Professional Learning Communities* (PLC) (Wenger, 1998) emerge as one of the most promising structures for professional learning, particularly when these involve collaborative inquiry (e.g. OECD, 2013; Ermeling, 2010; Nelson et al., 2008). *Professional Learning Communities* (PLC) emerge as one of the most promising structures for professional learning. FaSMEd teachers expressed the positive value of creating these environments, which are not always readily available in schools across Europe and South Africa.

FaSMEd policy guidelines

- The FaSMEd project found that the introduction of innovative technology to create a digital environment (between students, peers and teachers) can assist teachers in making more timely formative interpretations. We recommend the use of such technologies within classrooms to further enhance FA practices.
- Through the case studies there is evidence of teachers using technologies to gain information about their students' thinking, as well as to facilitate opportunities for students to learn from their peers. In interviews, students identified these practices as particularly beneficial in making their learning visible to the teacher, themselves and their peers. We recommend that technologies are utilised within classrooms to facilitate making learning more visible to all 'in the moment'.
- Our FaSMEd case studies show that most teachers opted for technology tools which were accessible and/or easy to learn how to use and apply in their classrooms. We would therefore recommend that when embarking on new technological innovations, the usability of tools is considered.
- FaSMEd found that where existing infrastructures supported the use of technology, schools were able to make considerable progress in their use of technology to support FA practices. We would recommend investment in the networking and wireless systems, together with technical support in schools. FaSMEd believes this is a priority and a pre-requisite for the implementation of this technology on a larger scale.
- Where teachers were able to work as professional learning communities, conditions were effective in enabling them to feel safe to experiment, examine the impact of their innovations, to talk openly and to establish principles about effective student learning. FaSMEd would therefore recommend that schools (wherever possible) facilitate time and space for teachers to plan, and reflect on their practice. A commitment to this from school leaders is crucial.

Future technological developments

The FaSMEd project explored the potential of technology to facilitate FA in mathematics and science classrooms. By introducing innovative technology, we created environments which enhanced connectivity and feedback to assist teachers in making more timely formative interpretations. A key element of teaching using assessment and intervention relates to the quality of the information generated by the various feedback loops that exist in the classroom setting and the involvement of the students within this process. The potential of the technology to represent knowledge in a meaningful way was perceived to be especially beneficial to lower achieving students, as it allowed them to represent their learning pictorially. Students could make sense of images and videos within a particular application (e.g. iPad application Popplet). We recommend that future research explores further applications that enable visual representations in mathematics and science.

Many of our teachers used technology with polling systems in order to gather evidence of student learning. Multiple choice questions have become one of the ways teachers seek out feedback on the understanding of their students, but these need careful framing, interpretation and response by the teacher. One possible problem is that single response multiple choice questions may not give a very accurate indication of students' understanding if a significant number choosing the right (or wrong) answer at random. A more accurate use of multi-choice would be to design questions where the correct answer is to select two (or more) choices simultaneously – thus reducing the probability of random choice being correct and a richer selection of information. Further research of these tools and possibilities is needed, the Bear Centre, UC Berkeley (USA) are currently working in this area.

Another issue is that current assessment and polling software often aggregate the data from groups of students, but do not do any further processing. Interpreting and reacting to such data is one of the major challenges for teachers. We recommend that future research into technology that can work intelligently with student responses, recognising common errors and suggesting strategies and/or feedback is needed. The potential for this is possible through drawing upon mass datasets of student learning behaviours that could exist and be utilised. The work done by the University of Duisburg-Essen (Germany) in FaSMEd goes some way towards this goal, albeit directed towards giving feedback to individual students. Also the DAE system developed at Utrecht University (Netherlands), which at the moment is used for teacher FA, could conceivably be enhanced to interact with the student responses in this way. We believe that future technologies have the potential to facilitate complex and authentic mathematical and scientific tasks and recommend future research to investigate these possibilities.

Learning from research findings

The main objective for FaSMEd was the development of a Toolkit for teachers and a Professional Development package to support it. In the course of the three year project a prototype toolkit was developed and evaluated leading to the production of the final toolkit. However, this resource has not been evaluated and it remains an open question about the extent to which a website incorporating the resource will be used or valued by teachers. Hence it is clear that, in order to ensure that the FaSMEd toolkit is fit for purpose, a further iteration would be required, including feedback from teachers on the use of the resources. Additionally, further research is needed to explore the FaSMEd case study schools and teachers to discover whether there has been any sustained impact of the project. We believe that investigation into whether teachers use resources such as online Toolkits, PD packages, classroom materials, etc., and if used, how and why they engage with such materials to support teaching is necessary.

The FaSMEd Toolkit now sits alongside the resources developed by other EU funded projects:

- SAILS: a collection of 19 SAILS Inquiry and Assessment Units which showcase the benefits of adopting inquiry approaches in classroom practice, exemplify how assessment practices are embedded in inquiry lessons and illustrate the variety of assessment opportunities and processes available to science teachers.
- MASCIL: an online collection of classroom materials and professional development materials that encourage and support teachers to implement inquiry-based learning (IBL) and make effective connections to the world of work (WoW) in their mathematics and science classrooms. The mascil project has developed two on-line toolkits. These are for use with (i) groups of in-service teachers and (ii) pre-service teachers who are on courses leading to becoming a teacher.
- PRIMAS: Professional development materials; Classroom materials for direct use by pupils; A range of professional development courses and other opportunities for teachers to explore effective teaching methods.
- ASSIST-ME: provides a research base on effective uptake of formative and summative assessment for inquiry-based, competence oriented Science, Technology and Mathematics (STM) education and formulates guidelines and recommendations for policy makers, curriculum developers, teacher trainers and other stakeholders in the different European educational systems.

In relation to mathematics and science education, then, there is clearly a great wealth of research and knowledge generated across Europe (and beyond). Whist at project level there has been some knowledge exchange and collaboration, more needs to be done to ensure that cross-project findings are integrated and translated into research, policy and practice. We recommend that such meta-analysis is essential for future research.

Working collaboratively

Throughout the FaSMEd project we were committed to a socio-technical approach, characterised by iterative, collaborative, process-focused activities and the engagement of participants in systematic reflection and evaluation at all stages of development. We believe that this approach has been particularly valuable as it provided the basis for collaborative research between practitioners and university researchers. Building on the principles of co-production this has been important in developing a Toolkit (Deliverable 3.3) and a Professional Development Package (Deliverable 3.6) that have emerged through practice. We were keen to place teacher agency at the heart of our methodology, recognising that any change in practice advocated by FaSMEd should be situated in the contexts of teachers, schools and existing educational environments. Throughout the project we tried to ensure that relationships between teachers, students and researchers were negotiated so that teachers and students could develop a genuine sense of agency and ownership of the research. This process is documented through the partner case studies (Deliverable D4.3) which provide a narrative of the experience together with the re-designed classroom activities and tools. The FaSMEd Toolkit website and Professional Development package (www.fasmed.eu/) are designed for teachers and/or teacher educators to actively engage with the FaSMEd tools and activities. We would recommend that this methodological approach to knowledge exchange and production is crucial for future classroom research.

Finally, we recognised from the start that the student perspective in FaSMEd was important. To this end, all partners interviewed students about their experiences and perspectives of the FaSMEd lessons, the activities and tools used, their attitudes towards mathematics and/or science and the use of FA and technology. Newcastle University also engaged with one class to design and produce a reflective FaSMEd Comic. The student view is not always adequately explored and represented, and we believe more should be done to facilitate this. In particular, we would argue for the design and co-production of student guides in future research.

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