D 5.2 Cross comparative analysis of case studies

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Index

Introduction

Over the past decade there has been a growing awareness that technology can support teaching student learning of mathematics and science. For example, the general guidelines of the role of technology in teaching and learning mathematics stated in the *Principles and Standards in School Mathematics* (National Council of Teachers of Mathematics- NCTM, 2000) under the Technology Principle:

- Technology enhances mathematics learning.
- Technology supports effective mathematics teaching
- Technology influences what mathematics is taught (p.25-26).

This is likely to be also true for students with difficulties in mathematics, and low achievers, in particular if it is used to assist with formative assessment (FA) practices (NCTM, 2007). Amongst the six effective strategies (visual and graphic depictions of problems; systematic and explicit instruction; student think alouds; use of structured peer-assisted learning activities involving heterogeneous ability groups; formative assessment data provided to teachers; formative assessment data provided directly to students) for teaching students with difficulties in mathematics, two are linked to formative assessment (e.g. FA data provided to teachers; FA data provided directly to students), and technology can definitely help to provide those.

The aim of the FaSMEd project links squarely to that: it aims **"to research the use of technology in formative assessment classroom practices in ways that allow teachers to respond to the emerging needs of low achieving learners in mathematics and science so that they are better motivated in their learning of these important subjects"** (Project Description of Work). More precisely, consortium partners will "adapt and develop existing research-informed pedagogical interventions (developed by the partners)" (ibid) for working with learners/students and helping to transform teaching. Moreover, the project will report on the varying assessment tools, and the pedagogic/didactical practices associated with these tools, seeking to "reveal the educational opportunities that are open to these students" (ibid). This, it is suggested, is likely to "expand our knowledge of technologically enhanced teaching and assessment methods", also addressing low achievement in mathematics and science. Ultimately, the objective is that a greater number of students will have more positive experiences and formative assessment support, and hence develop more positive dispositions towards further study of these subjects (and perhaps develop the desire to be employed in related fields).

Research questions to be addressed as a theme across the project (and answered in a summary in WP6) were:

1- How can research-informed approaches help to understand and address key challenges in enhancing participation, engagement and achievement in science/ mathematics [in particular to address differences linked to socio-economic status, gender, and ethnicity which appear to be linked to low achievement]?

2- What specific new interventions, or changes in policy or practice, offer the greatest potential to improve engagement and learning in science / mathematics and how could their potential effectiveness and feasibility be assessed more fully?

The purpose of WP5 is "to elaborate a systematic comparative analysis of the results and findings emerging from the assessment of existing experiences and the newly developed interventions". For this we used the "products" (e.g. results and findings) of WP2, WP3 and WP4, and the main anchors for the analyses of D5.2 were the consortium members' case studies (see D4.3).

1. Description of the methodological and analytical approaches: theory and practice

The case studies from WP4 (analysed in WP5) reported (and were based) on the following questions:

- How do teachers process formative assessment data from students using a range of technologies?
- How do teachers inform their future teaching using such data?
- How is formative assessment data used by students to inform their learning trajectories?
- When technology is positioned as a learning tool rather than a data logger for the teacher, what issues does this pose for the teacher in terms of their being able to become more informed about student understanding?

These research questions formed the basis for our research design, that is a "case study" design (see Yin 2004), and the associated data collection strategies. In D5.1 ("Methodology") we proposed a common methodological approach for the cross-comparative analysis drawing upon the findings of the groups.

'he unit of analysis was the teacher with his/her mathematics/science class, each forming one case. In terms of mathematics/science content, we stipulated that at least one lesson sequence (of one teacher) should be on "graphs/functions" (see "travel graph" activity). The context/ school environment description was based on tree kinds of information:

1) contextual information of (at least two) schools;

2) teacher demographic information;

3) student demographic information- these data were used for D5.3.

Moreover, as described in D5.1, each case study was anchored in the following data, which in turn were linked to the relevant research questions. In short, we had (for each mathematics and science teacher case) the following data:

- description of technology tool/s and observation of its/their use/s;

- teacher report/logs on a series of lessons, including the "graphs/functions" lesson/s;
- observations of series of lessons/teacher (including the "graphs/functions" lesson/s);
- interviews with participant teachers;
- interviews with selected participant students, and selected focus group interviews based on q-sorting activities;
- local student attainment data (teacher assessment) from the teachers/classes (e.g. tests).

Hence, the case studies produced by the consortium partners were anchored in these data. Each country partner team had produced between two to four intervention cases (see WP4) in mathematics and science education, and amongst those there was at least one case on the content of "graphs/functions". These case studies were conducted according to our specially developed and rigorous methodological schedule for data collection (see description in D5.1). Subsequently, these cases were the main anchors for the cross-comparative analyses, i.e. deliverable D5.2.

In terms of theoretical and analytical frames, we had proposed a frame (D5.1), which consists of two tiers. In summary, this frame has the following two strands:

(1) Chevallard's Anthropological Theory of Didactics (ATD- see Chevellard 2005), which provides tools for the description of mathematical/science activities in terms of "praxeologies", as a way to describe mathematical or scientific organisations at different levels (pleases see D5.1 for further explanations and descriptions of ATD). Considering the work of Chevallard (2005), a learner encounters a given mathematics/science knowledge in an institution (e.g. school) and in a particular context (e.g. region/country). The institution/school (and learning environments) frames this knowledge, and this framing entails several components. Hence, ATD helped us to see students' (and teachers') praxeologies in contexts of the different countries. To a large extent this frame was used for the analysis resulting in the deliverable D5.3, but of course it also underpinned, and provided the contextual analytical frame for our case study analyses.

(2) As we had a specific interest in the links between the formative assessment, teachers' and students' activities when working with the mathematics/science, and the technology resources/tools intervening in the mathematic/science works, we leaned on the instrumental/documentation approach (see Trouche, 2004; Guin, Ruthven, & Trouche, 2002; Gueudet & Trouche, 2009; Pepin, 2014, in mathematics education) to didactics as a suitable framework. In principle, the instrumental/documentation approach to didactics is based on the idea of "mutual adaptation", where teachers (or pupils) interact with the resources/tools. In that process/interaction the teacher/pupil is influenced by the affordances and constraints of the tool/resource, whilst at the same time the tool/resource is "influenced" and shaped by the teacher/pupil, as illustrated in the figure below.

In principle, the instrumental/documentation approach maintains two main concepts, introduced by Rabardel (1995): *instrumentation*, *instrumentalisation* (Figure 1). For performing a teaching task, a teacher (or student) interacts with a set of resources. This interaction combines two interrelated processes: the process of *instrumentation*, where the selected resources support and influence the teacher's (or student's) activity; and the process of *instrumentalisation*, where the teacher (or student) adapts the resources for his/her needs. To further explain, the *instrumentation* process is the process whereby the (affordances and constrains of the) tools and resources influence and support the teachers (or students) in their instructional tasks. The *instrumentalisation* process is the process whereby the teacher appropriates and changes the resource/tool.

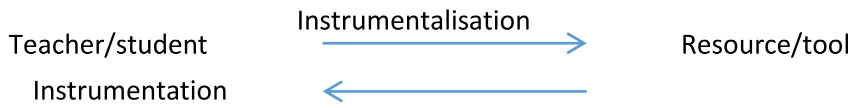


Figure 1. The instrumentation/instrumentalisation process

According to the theory, a resource becomes an instrument (or document) when it is combined with the usages of the teacher/student:

Resource/tool + teacher/student usages = Instrument (or Document)

Our analyses were broadly divided into two levels: (1) within-case analysis; and (2) cross-case analysis (Cohen, Manion, & Morrison, 2000). In terms of (1), we analysed the teacher (and their class) cases individually, and each consortium partner has written up at least two cases (based on the questions/grid provided, to have comparable data for analysis). These cases were then analysed in terms of cross-case analysis (2). In order to analyse the interactions in the classroom, the instrumental/documentation analytical approach was used (whilst the ATD approach was used for the 'larger picture', i.e. D5.3). These processes of comparing similarities and differences within and across cases were conducted within each country, before turning to the cross-case comparative international analysis.

For the within-case analysis, consortium partners found it helpful to add a "positioning" tool (as described and presented in D4.3), as it helped them to position the three "dimensions" under study (i.e. participants; Formative Assessment strategies; functionality of technology) in relation to each other.

In developing a two-layered analytic framework (within- and across- case analysis) used in the study, we pursued an iterative approach that combines results from the literature/theoretical frames with our investigation of:

(1) teachers' use of formative assessment/technology tools; and

(2) pupils' use (and perceptions) of formative assessment strategies/tools for their learning.

Hence, and in line with the main aims of the study, namely "to research the use of technology in formative assessment classroom practices in ways that allow teachers to respond to the emerging needs of low achieving learners in mathematics and science so that they are better motivated in their learning of these important subjects", the research design had two strands, and connected analyses. Formative assessment tools (in particular technology tools and resources) were examined with respect to their use by (a) teachers and (b) pupils, and the links between these. Each of these strands was then analysed cross-nationally/regionally, and considering their respective environments.

In previous meetings (e.g. in Turino) the consortium partners had commented on the research design and analytical approaches. In Cape Town (February 2016) each partner team presented their main insights from their within-case analysis. In workshops (at the Cape Town meeting) WP5 suggested a table to help analyse from the within-case analysis to the cross-case analysis. The table had four strands/columns:

1. Technology tools/resources
2. Teacher beliefs and interaction with the tools/resources (including functionality of technology)
3. Formative assessment practices (teacher and/or student)
4. Pupil beliefs and interaction with the tools/resources (including functionality of technology)

This helped to see the connections between the digital resources/tools, the teacher and pupil interaction with those tools, and the formative assessment practices/activities, which in turn supported the instrumentation/documentation analysis (see ENSL table in Appendix 1).

In subsequent personal and Skype meetings/discussions (e.g. Norwegian/NTNU & French/ENS) the results from the comparative cross-case analysis were discussed, anchored in the intervention cases of each country's cases and their within-case analyses.

It has to be emphasized that the consortium schools and teachers participating in the project used very different technological tools in their mathematics and science classrooms, and of course teachers in the different countries worked under different conditions and in different environments, as evidenced in D5.3. Hence, a "true" comparative analysis is not possible, as many variables change with the use of different tools, change of environment, etc. As we outlined in D5.1, "we will not try to compare teachers internationally, but rather to develop deeper insights into the phenomena under study, i.e. formative assessment strategies (in particular technology-based) can help teachers and students to develop better learning trajectories."

2. Findings

Looking over the case studies, mathematics and science teachers of the project used a variety of technology tools and resources (e.g. OneNote on tablets; Maple TA on tablets; tablet with classroom connected technology (IDM-TClass & Interactive White Board-IWB); Excel spreadsheets; Ipads & *Socrative*; IPad, IWB & application, such as *Educreations* or *Popplet* or *Showbie* or *Kahoot*; IWB & video or Google form), sometimes working with several tools in one lesson. We cannot argue that one tool worked better than another, but that the use of the tool/s in a meaningful way, for teachers and students, and with clear objectives, seemed to determine the "success" of the interactions in terms of formative assessment practices.

Let us now come to the findings from our case studies in terms of the technology tool/s and their use. In the following we outline and group our findings in statements, and we explain and evidence each claim in a subsequent section.

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

Looking across the cases, it was clear that the technology tools provided immediate feedback:

(1) 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 (see D4.3, UU case 1 & 2), the DAE tool provided opportunities for collecting and processing students' summative results, and subsequently for further analysing individual student work. As another example, a mathematics teacher (D4.3, UNITO, p.95) mentioned that "other effective moments are the polls, since they are immediate and interesting."

(2) for pupils in terms of summative assessments. For example, in the case of the IPad being shared by the teacher and students (with *Reflector and Showme* software) (see D4.3, UNEW case 1, p.15), it was noted that the attitude of students to the summative assessment was generally positive. Students felt that examination results showed them "what I need to do to improve things" (student 2) and "how you have improved throughout the year" (student 3). In another case (UNOTT, case 1, student interviews) students "saw the benefits of being able to revise topics independently with immediate feedback".
One teacher said: "Students especially appreciate to have instant feedback (feedback which can be individual or collective)." (D4.3- Part B, p.266)

At the same time selected teachers (e.g. UU case 1) apparently "relied heavily on the researchers", to help plan their lessons in terms of connecting FA and technology (see later). In another case (UNOTT, case 2) there appeared to be "little evidence that teachers or students actually used all the information generated effectively".

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 cooperation between individual students/within groups.

Nearly all the cases studies reported on the positive effect of technology in terms of facilitating and encouraging classroom discussions, either between teacher and students, or amongst students. That's how it had been perceived by students in particular (e.g. D4.3- Part A, p.17) when reporting that "students thought that the use of technology in lessons encouraged more discussion and this was seen as helpful."). In the same class, and over different lessons, students appeared to have had ample opportunities for peer interactions, partly due to the technology, in terms of: (1) paired discussions; students compared samples displayed, interpretations and strategies from peers, suggestions from peers, solutions, working and explanations from peers.

This is in principle a positive result, but of course it has to be examined with respect to whether it was actually the technology tool that afforded the discussions, or the curriculum materials (e.g. graphs/functions lesson) supporting and integrating the use of technological tools. From the South African cases, where no or hardly any technology tools (except for projection) were used, it was noted that the activities proposed "made [students] think" (D4.3-Part B, pp711-717 & p.835). Here students also reported that the activities were "different to normal classroom activities", also using particular words that they apparently were not used to (e.g. "practical", "active").

This leads us to re-consider our conceptualization of "technology tool". Leaning on the research literature of technology and/in mathematics education (e.g. Ruthven, 2014; Roschelle, Rafanan, Estrella, Nussbaum, & Claro, 2010), we note that "technology can support both computation and representation" and that technology can in particular support mathematical ideas "in ways that are important for conceptual understanding" (p.837, ibid). Linking to the specific common task/module on "graphs/functions", a representational approach (Kaput, 1992) can be taken in which technology/computers are seen as supporting new visualisations of and interactions with (mathematical) objects. For example, graphical representations (e.g. graphs, animations) are often juxtaposed with linguistic representations (e.g. text, algebraic symbols). It is argued in this approach that because mathematical concepts are abstract but human minds develop concepts from concrete experiences, we can often best come to understand an abstraction by interacting with multiple concrete embodiments. In this sense the technology tool and the "card tool" (as in the South African case) become different representations of the abstract concept of "functions", and hence can be seen "doing the same job" for supporting the development of the concept of "functions". At the same time the divides between "strictly technological" tool and curriculum material tool (in this case for different representations) become blurred (which in turn justified our combination of Instrumental/Documentation Framework analysis).

Statement 3

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

For us (as teacher educators and researchers) this finding was surprising, and it was only evident in particular cases. At the same time we regarded it as an important finding, in particular as this came from student interviews, i.e. was expressed by students:

"You made a mistake, that's all, but you know that you have understood." (D4.3- Part B, p.359)

"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." (D4.3 – Part B, p.387)

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

"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 …" (D3.4- Part B, p.454)

Representing their knowledge in a meaningful way was perceived to be especially beneficial to low-achieving students, as it allowed them to represent their learning "pictorially". Students could make sense of images and videos within a particular application (in this case iPad application *Popplet*), which would not have been possible with a pen & paper graphic organizer (D4.3- Part B, pp.422-423).

Statement 4

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

The literature on the integration of technology in mathematics and science teaching (e.g. Ruthven, 2014; Black & Atkin, 1996) emphasizes how integration of new technologies depends to a large extent on the teachers adapting and developing appropriate knowledge and skills to underpin their classroom practice. Several frameworks (e.g. TPACK- Koehler & Mishra, 2009; Instrumental Orchestration Approach – Trouche, 2004; Structuring Features of Classroom Practice framework - Ruthven 2009) have been devised to identify, analyse and support the teaching expertise needed for the integration of technologies in classroom practices. However, what we found in this study is different, in the sense that teachers see the technological tools as "opportunities":

- *opportunities for changing practices*, in the sense that teachers expanded 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 formative assessment is] gathering information at all steps of the teaching act." (D4.3-Part B, p.265)

- *opportunities for adapting 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." (D4.3- Part B, p. 387)
  Another teacher, although questioning was his predominant approach, 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". (D4.3- Part B, p.81)

Statement 5

The technology helped to raise issues with respect to FA practices (for teachers and students), which were 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.

This, of course, links to the previous statement/s. However, we want to foreground now FA practices (and teacher awareness of FA practices). Analysing the intervention cases, one could identify the five FA strategies outlined by Black and Wiliam (2014), i.e.

A Clarifying learning intentions and criteria for success (teacher)

B Engineering effective class-room discussions and other learning tasks that elicit evidence of student understanding (teacher)

C Providing feedback that moves learners forward (teacher)

D Activating students as instructional resources for one another (peer)

E Activating students as the owners of their own learning (learner)

in all cases (albeit not all strategies in all lessons). In our earlier explanation of analytical frames (and in D4.3) these five FA strategies have been used to position the dynamics in the classroom. This has been represented in a three-dimensional matrix:

- dimension x- FA strategies;
- dimension y- participants (teacher, peer/group, student/individual);
- dimension z- three functionalities of the technology (sending & sharing, processing & analysing, interactive environment).

Usefully, and in connection with our table (see earlier description of analyses), the information from consortium members could usefully be visualised and categorised in the provided grid, and selected members (e.g. ENSL) produced visual positionings of the dynamics of the three (above mentioned) dimensions in any particular lesson (see Instrumentation analysis table of ENSL in appendix).

As examples (from this case analysis) of the FA strategies observed in this case, we can see that all five strategies (A-E) were evident in the lessons of the science teacher, for example:

A- the teacher comments on questions for clarifying learning objectives and criteria for success (students are individually informed about such the criteria);

B- the teacher designed diagnostic tasks for students: questions on target competences;

B- the teacher engineered classroom discussions;

C- the teacher provided feedback on students' answers and on strategies for moving them towards answers;

D- Students were activated as instructional resources for each other during class discussion;

E- Students were activated as instructional resources for each other, as owners of their own learning.

These FA practices were then associated with particular functionalities of the technology tool/s: for example, B with "sending and displaying" questions; and with "displaying students' answers". With reference to D and E practices, the teacher mentioned:

"Before my participation to the FaSMEd project, I was curious about technology in classroom. When I discovered the first dynamical geometry software I saw the potentialities of GDS. I also understood that with a beamer I could share this software with students without having to move to the computer lab, that is sometimes difficult. I was convinced that it was time saving, despite it's often difficult to get familiar with." (D4.3- Part B, p 316/7)

Students also changed perceptions on the usefulness of the technology for their learning; they felt that working with these tools helped them to improve their learning, and facilitated their understanding of mistakes (D4.3-Part B, p. 358-359). In the above case 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, that is they realised that mistakes could be useful as sites for their own learning:

"You made a mistake, that's all, but [now] you know that you have understood." (D4.3- Part B, p.359)

The teacher of this class argued that the technology:

"allows to motivate some students. All this information allows to validate, or not, the teacher's feelings regarding students' understanding. It also gives an opportunity for students to situate themselves. So, it allows to clarify learning goals." (D4.3- Part B, p.317)

Statement 6

Different technological tools provide different "outcomes": in principle, each tool can be used in different ways, and hence the instrumentation/instrumentalisation processes are important. (e.g. feedback to individual; feedback to groups of students; feedback to whole class and discussion) Often a mix of technology was used, and the "orchestration" of the technology tools needs particular skills.

It became clear that different technologies provided different affordances and constraints, in terms of FA practices and student learning opportunities for pupil learning. Each technology tool could be (and has been) used/applied in different ways. This is supported by the literature, e.g. Artigue and Bardani (2010):

“When presented with the TI-*n*spire, we assumed that these developments could offer new possibilities for students’ learning as well as teachers’ actions. They could foster increased interactions between mathematical areas and/or semiotic representations. They could also enrich the experimentation and simulation methods, and enable storage of far more usable records of pupils’ mathematics activity. However, we also hypothesized that the profoundly new [sic] nature of this calculator and its complexity would raise significant and partially new instrumentation problems both for students and teachers and that making use of the new potentials on offer would require specific constructions, and not simply an adaptation of the strategies which have been successful with other calculators. “(Artigue & Bardini, p. 172)

The Instrumentation/instrumentalisation theory (see Trouche 2004) puts it in a short form (as explained in the previous section):

tool/resource + utilization (scheme/s) = instrument

In other words the “naked” tool (or resource), such as for example a clicker or iPad, used in a particular way, becomes an instrument for a particular purpose (for student learning, for example). This means that the scheme of utilization becomes the determining factor for the “outcome” (the instrument), and hence teachers’ goals and perceptions, as well as their beliefs and habits of mind, in this case of FA and its practices, are so important and influential. It appeared that insufficient awareness and knowledge about FA and the formative use of technology tools led to a “procedural way” of using the technology tools (e.g. D4.3- Part B, p.225-226).

Moreover, we could see in our cases that the influence not only went from the teacher to the tool, but the teacher was also influenced by the affordances and constraints of the tool: “Instrumental activity in technological settings is multimodal, because action is not only directed towards objects, but also towards people” (Arzarello & Robutti, 2010, p. 718).

Statement 7

Technical and logistical factors appear to constrain the implementation and use of technology for FA purposes.

In our cases several teachers reported that particular technical difficulties, e.g. for setting up the technology, or for 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. As quoted before, one teacher suitably commented:

“[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. 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 then 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. “(D4.3- Part B, p.265)

In addition, unstable or lacking wifi connectivity was still a hindrance for more widespread use of such technological tools that depend on it (e.g. clickers, Socrative or Kahoot). Moreover, time constraints also seemed to cause problems for some teachers, for example too little time was reported to prevent some teachers from using more technology for FA, and this lack of time appeared to lead to procedural ways of using the technology (e.g. D4.3- Part B, p.225-226).

3. Conclusions

In this section we go back to the research questions, i.e.

(1) How do teachers process formative assessment data from students using a range of technologies?

(2) How do teachers inform their future teaching using such data?

(3) How is formative assessment data used by students to inform their learning trajectories?

(4) When technology is positioned as a learning tool rather than a data logger for the teacher, what issues does this pose for the teacher in terms of their being able become more informed about student understanding?

and answer them using the evidence from our findings (see previous section) which are in turn anchored in the intervention cases (D4.3).

Regarding (1), we conclude that most mathematics and science teachers in our study were not used to process formative assessment data (from students) using a range of technologies: most had little or no knowledge of the different tools that could be used, and indeed helpful practices associated with the use of technology tools and formative assessment. In short, this aim is not yet well realised and there is much room for improvement: both in terms of ergonomics with respect to the technology tools, as well as in terms of teacher professional development to helpfully build in such tools into teacher formative assessment instructional practices.

Regarding (2) and linking to (1), there were few teachers in the study who could be said to have informed their teaching with such student formative assessment data. With the help of the project, selected teachers managed to build the formative assessment tools into their teaching ("at every stage of the instruction process"), and these seemed to have a lasting effect (see ENSL mathematics case). In most cases, however, we saw attempts to use the technology, but these were not further seen through to subsequent stages of the formative assessment process: for example, summative data were stored, for not used formatively in subsequent steps. In short, we argue that this aim has not been realised in most countries' cases, and we predict that there are major challenges ahead.

Regarding (3), our investigations (and interventions) have shown a relatively positive picture: students seemed to welcome the formative assessment data provided by the technology (and the teacher/s) and they were ready to usefully build it into their learning strategies. Overall, the picture was of course far from perfect, but we could identify (and follow through) selected promising patterns (e.g. UNOTT case/s), in particular for low achieving students (e.g. NUIM case/s).

Regarding (4), it became clear, and this is supported by the literature, that unless teachers were experienced and confident teachers of mathematics/science (with high level of pedagogical content knowledge, as perceived by peers), the combination of formative assessment practices and technology for the purpose of becoming more informed about student learning and understanding was a daunting task. We argue that more resources need to be invested for enhancing teachers' pedagogical content knowledge (PCK/TPACK) in connection to formative assessment practices.

In summary, we argue that the success of the technological resources/tools for FA is to some extent influenced (limited) by suboptimal characteristics of those resources/tools, and hence, their optimization seem desirable. However, more decisive appeared to be the didactic (PCK and TPACK) capacity of the teacher in (inter)acting with these resources/tools, and hence more professional development is needed in that respect. Nevertheless, we could identify selected promising approaches emerging from our case studies. The least problematic finding seems to be the learners' attitude and behaviour. They seem sufficiently prepared and ready to benefit from the affordances of ICT for FA.

References

Artigue, M., & Bardini, C. (2010). New didactical phenomena prompted by TI-NSPIRE specificities: The mathematical component of the instrumentation process. In V. Durand-Guerrier, S. Soury-Lavergne, & F. Arzarello (Eds.), *Proceedings of the sixth congress of the European society for research in mathematics education* (pp. 1171–1180). Lyon: Institut National de 578 Recherche Pédagogique.

Arzarello, F., & Robutti, O. (2010). Multimodality in multi-representational environments. *ZDM The International Journal on Mathematics Education, 42*(7), 715–731.

Black, P. J. & Atkin, J. M. (Ed.). (1996). *Changing the subject: innovations in science, mathematics and technology education*. London: Routledge in association with OECD.

Black. P. & Wiliam, D. (2014). Assessment and the Design of Educational Materials*. Educational Designer, 2*(7), 1-20.

Chevallard, Y. (2005). Steps towards a new epistemology in mathematics education. In M. Bosch (ed.), *Proceedings of the fourth congress of the European Society for Research in Mathematics Education*. Sant Feliu de Guíxols: CERME 4.

Cohen, L., Manion, L., & Morrison, K. (2000). *Research Methods in Education* (Fifth edition). London and New York: Routledge.

Gueudet, G., & Trouche, L. (2009). Towards new documentation systems for mathematics teachers? *Educational Studies in Mathematics, 71*(3), 199-218.

Guin, D., Ruthven, K., & Trouche, L. (Eds.). (2005). *The didactical challenge of symbolic calculators: Turning a computational device into a mathematical instrument*. New York: Springer.

Kaput, J. J. (1992). Technology and mathematics education. In D. Grouws (Ed.), Handbook on research in mathematics teaching and learning (pp. 515-556).

Koehler, M.J. & Mishra, P. (2006) Technological Pedagogical Content Knowledge: a framework for integrating technology in teacher knowledge. *Teacher College Record, 108* (6), 1017-1054.

NCTM (2000) *Principles and standards for school mathematics*. Reston, VA: National Council of Teachers of Mathematics.

Pepin, B. (2014). Re-sourcing curriculum materials: in search of appropriate frameworks for researching the enacted mathematics curriculum. *ZDM: The International Journal on Mathematics Education*, *46*(5), 837-842.

Roschelle, J., Rafanan, K., Estrella, G., Nussbaum, M., Claro, S. (2010) From handheld collaborative tool to effective classroom module: embedding CSCL in a broader design framework. *Computers & Education, 55* (3), 1018–1026.

Ruthven, K. (2009) Towards a naturalistic conceptualization of technology integration in classroom practice: the example of school mathematics. *Education & Didactique, 3*(1), 131-149.

Ruthven, K. (2014) Frameworks for analyzing the expertise that underpins successful integration of digital technologies into everyday practice. In A. Clark-Wilson, et al. (eds.), *The mathematics teacher in the digital era.* (p. 373-393). Dordrecht: Springer Science & Business Media.

Trouche, L. (2004). Managing the complexity of human/machine interactions in computerized learning environments: guiding students' command process through instrumental orchestrations. *International Journal of Computers for Mathematical Learning, 9*, 281-307.

Yin, R.K. (2004) *The Case Study Anthology.* Thousand Oaks, London & New Delhi, Sage Publications.

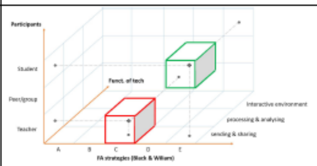
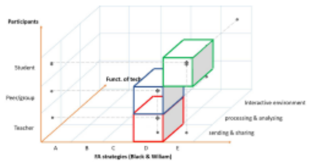
Annexe 1

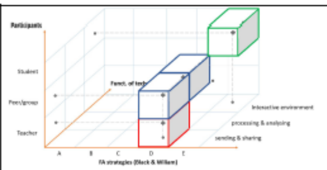
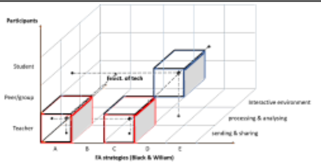
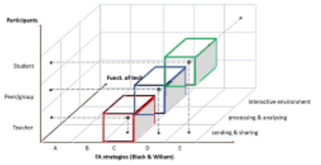
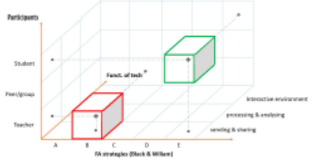
Fasmed comparative analysis table/s

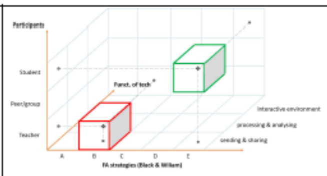
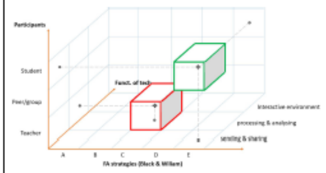
	Country & national frames (e.g. nat. curricula, teacher guides, textbooks etc.) - national policies concerning digital resources/technology - national policies concerning formative assessment/pedagogic practices	School environment (e.g. school organization; level of schooling; etc.)	Formative assessment/pedagogic practices	Discipline (e.g. mathematics; science)	Any particularities of the learning environment
ENSL	Strong encouragement of national ministry of education for using technology within the classroom. No national policy concerning formative assessment, but general incitement for having a student-centered pedagogy and a participative learning.	Collège Fontreyne is a low secondary school of a small town in South-East of France (Gap). School population is summarized in the case study. Grade 9 class (students' age: 13-14), composed of 22 students with an average school level. The teachers declare that there is no difficulty in the class management. The class composition has been made with the will of creating a class with low achievers and medium students.	- Making the students work in group for fostering discussion and argumentation among students; - Collecting one production for each group; - Showing the different works and commenting them with the students; - Using different tools for managing the groups' work and the individual work; - Providing feedback both individually and about the class' progression.	Maths	Tablet-using classroom, where each student uses her tablet every day, in every subject, only at school.

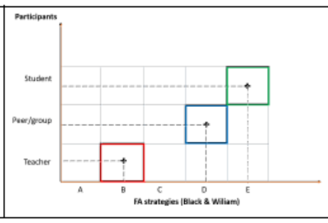
Instrumentation/documentation analysis

ENSL Case study in maths - distance/time graphs (D4.3-part B,pp.256-310)

Tools/resources, in particular digital tools/resources	Teacher interaction with digital tools/resources (e.g. see also functionalities of technology) Teacher comment /perceptions of its value for teaching & learning mathematics (& science) (e.g. pre- and post Fasmed intervention)	Formative assessment practices (e.g. see FA strategies) teacher & pupil: specify	(pink) Pupil interaction with digital tools/resources (e.g. see also functionalities of technology) & Student perception/comment of its value for learning mathematics (& science)	Dynamics	Pupil perceptions of learning and/or achievement
OneNote on tablets	Orchestrating the students' work in groups.	Teacher provides feedback to each student in the group or asks students to provide feedback for each other (C) Students act in the group as the owners of their own learning and/or as instructional resources for one other (E and D)	In each group, one student writes on her tablet the proposal agreed in the group while the others take note either on their notebook or their tablets.	 	*Technology* - It appears that the presence of technology is very controversial in the class (D4.3-part B,p.304) - Students are torn between the pleasure to work with tablets and the difficulties that they encountered or the necessary change in their learning habits (D4.3-part B,p.305)

	Orchestrating the students' work in groups. Institutionalising students' work results.	Teacher encourages students to act as instructional resources for one other (D) Students individually work on their tablets as owner of their own learning (E)	Students share and analyse their work on their tablets in the group. Students individually interact with the dynamic environment provided by the technology.		*Mathematics* Students expressed a very positive attitude about both maths learning and the place of maths in their life. Students referred to mathematics as a school subject rather than mathematics as a science (D4.3-part B,p.306) *Work in group* Most of the students like to work in group and consider that it helps them to better understand mathematics (D4.3-part B,p.306) *Assessment* Students became aware of the opportunity for teachers to follow their work in class but do not necessarily make
NetSupport school for networking tablets to the classroom computer, connected to the IWB	- Collecting students' work making screenshots of their tablets, working directly on the classroom computer; - **Displaying** and sharing students' work at the IWB; - Inviting students to amend/clarify their proposal, **saving** modifications on the IWB.	Students are activated as instructional resources for one other (D) Teacher draws on these comments to clarify the learning objectives (A) and provide feedback to students (C) Individual students receive feedback on their own work (E)	Students analyse their own work or the classmates' work, by adding information, **interacting** with the IWB.	 	
	The same use of technology without inviting students to amend their proposal. T: "*[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 formative assessment is] gathering information at all steps of the teaching act*" (D4.3-part B,p.265) T: "*There were some technical difficulties related to the handling of the material, during the first two months of FaSMEd project. Today I see only advantages of using digital technologies for formative assessment.*" (D4.3-part B,p.265)	Teacher designs new learning tasks that elicit students' understanding (B) Students solve the task as the owner of their own learning (E).	Students individually analyse the work of the class that is shared on the IWB.		the link with the possibility of personalized assistance throughout the year (D4.3-part B,p.308).

Maple TA on tablets, classroom computer connected to the IWB	- **Sending** questions to students and **storing** their answers;	Teacher designs learning tasks for students: 4 questions, one for each target competence (B) Students can see their progression through different tests, becoming owners of their own learning (E).	Students **fill in** the questionnaire, drawing on what they have learnt, and **submit** their answers on Maple TA		
	- **Displaying** the table/graph of students' results, **processed and analysed** by the software. T: "*Students especially appreciate to have instant feedback (feedback which can be individual or collective)*" (D4.3-part B,p.266)	Teacher provides feedback on the class' progression (C) Students individually can position themselves with respect to the class' learning (E)			

No digital technology is involved	Orchestrating students' work in groups, without using technology.	Teacher designs learning tasks for students (B) Students act in the group as the owners of their own learning and/or as instructional resources for one other (E and D)	Doing the activity in groups without using technology		

Other insights and/or questions:

The table didn't show the dynamical aspects of agents using formative assessment strategies with technology. So, we proposed to illustrate it with the sequence of cuboids within the three-dimensional model (see column "Dynamics").

Entering by the "tool" probably allows to follow the instrumental genesis of the teacher and the students, but hides the chronological moments of the implementation of the FA strategies. Therefore, we are able to grasp the local dynamics but not the global ones.

We cannot find the place for our conclusion (key issues, elements of answer) with respect to the 4 research questions of the project. For ex. where can we write that "The transfer of responsibility of knowledge construction to the students is facilitated by the possibilities given by technology both to experiment with mathematical objects through interactive environment and to share researches, ideas, conceptions and misconceptions between peers and with the teacher"?