ABOUT THE AWKWARD PROCESS OF INTEGRATING TECHNOLOGY INTO MATH CLASS

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This paper briefly reports and discusses the findings of some studies (carried out over the past years within our research group) on the use of technology in mathematics teaching and learning, thus taking the shape of an overall a posteriori reflection with the aim of promoting further development. The first study concerned teachers' perceptions of technology in math class. The second study aimed at investigating how teachers orchestrate activities in a technology-rich class. The aim of the third study was to analyse the relationship between work with manipulatives and technologically instrumented work within a laboratory approach. The important role of the teacher is highlighted, seeking to individuate the crucial factors influencing the awkward process of integrating technology into math class.

Keywords: Integrating technology, teacher's perceptions, teacher's role, teachers' training

INTRODUCTION

According to findings in the research field on technology in mathematics education, it can be assumed that technological instruments can play a crucial role in the teaching and learning process (Arzarello et al., 2006). Calculators, Interactive Whiteboards (IWB), and other technological tools, such as Dynamic Geometry Software (DGS), Computer Algebra Systems (CAS), applets and spreadsheets, can be considered as vital components of high-quality mathematics education in the 21st century. Scholars agree in believing that, thanks to the possibilities provided by the use of technology, a shift from processing algorithms and calculations to constructing models, reflecting, or evaluating results is possible during teaching and learning math process. For instance, it is possible to shift from using static representations to experimenting with dynamic and interactive modes of visualization and exploration (e.g. Holyles & Lagrange, 2010).

However, it is extremely important and urgent to understand and let teachers become aware of how, when and why technologies can influence, support and mould the way that students learn mathematics. This urgency is also justified, at least in Italy (as in many other countries), by the national policies aimed at fostering the integration of technologies (revising school curricula and lately, increasing the number of IWBs in all kinds of Italian schools). Although the use of technology in Italian schools is on the cutting-edge of the national policies, we contend that it must still be considered at the edge of a meaningful effectiveness in the teaching and learning of mathematics.

It could be said that an "adequate" integration of technology within classroom activities should bridge the gap between the planned curriculum and the ones implemented, enhancing mathematics teaching and learning (NCTM, 2000). This paper will focus on the meaning of the term "adequate" when referred to the integration of technology in math class.

RATIONALE AND RESEARCH QUESTION

In the mid-1980s, the ICMI Executive Committee launched a set of activities, named ICMI Studies, with the aim of contributing to a better understanding and resolution of the challenges that face multidisciplinary and culturally diverse research and development in mathematics education. For the very first ICMI Study the chosen topic was: "The Influence of Computers and Informatics on Mathematics and its Teaching". As Jean Pierre Kahane (President of the ICMI in 1985) recently explained, at that time it seemed evident that informatics was likely to have an important influence on mathematics education but many professional mathematicians were not yet convinced that it would have a substantial influence on their mathematical practices. Twenty years later, the scenery has radically changed:

> no one would deny the influence of informatics and digital technologies on the professional practices and life of mathematicians and on the mathematical sciences themselves, but regarding the influence on mathematics education, the situation is not so brilliant and no one would claim that the expectations expressed at the time of the first study have been fulfilled (Artigue, 2010, p.464)

so that the ICMI decided to return to the theme, launching an ICMI Study, the 17th, to be called "Digital Technologies and Mathematics Teaching and Learning: Rethinking the Terrain" (Hoyles & Lagrange, 2010).

As some scholars have underlined, various teaching and instrumental factors that foster digital technology integration can be identified. Assude and colleagues (2010), for instance, pointed out that among these factors, one concerns the didactical transposition, while another the problem of management in the classroom. In addition, the relationship between technical and conceptual mathematics must be taken into account.

In this paper we focus on the decision to use technology for teaching and learning maths that is an important responsibility for teachers. Their duty, indeed, is to find learning environments, activities, ways and tools that allow students to benefit from fields of experience (that are important and useful), and also promote socialization, a process in which students are encouraged to learn maths.

Herein, we attempt to answer the following research question: what are the crucial factors influencing the awkward process of integrating technology into math class?

THEORETICAL FRAMEWORK AND RELATED LITERATURE

In agreement with general results in this field, we believe that a strategic use of technology, by offering opportunities for change in pedagogical practice, could contribute to mathematical reflection, problem identification and decision making. However, technology cannot replace conceptual understanding, computational fluency or problem-solving skills, nor can it be taken for granted that technology alone can change essential aspects of teaching and learning (Mously et al., 2003). It is a well-known fact that the use of any kind of tools in a classroom, although they can help some students to find an explanation, is not enough to guarantee a permanent understanding, still less to promote conscious and thoughtful learning. If technology was used only as an auxiliary tool to generate and show images, expand human memory or increase the turnaround in feedback, it would be unable to foster the progressive construction of a personal heritage of meaningful mathematical knowledge, skills and attitudes.

For these reasons, it is extremely important that teachers understand and become aware of the affordances, constraints, and general pedagogical nature of technology as a new resource in relation to the specific mathematical topics addressed in school (Ruthven & Hennessy, 2002).

As part of the instrumental approach developed from the studies of Vérillon and Rabardel (1995), the "instrumental genesis" expression has been coined to reflect the long and complex process (at the same time social and individual, connected to the limits and potential of the artefact and to the student's qualities) during which a student turns an artefact into a tool, developing techniques and mental patterns that allow him to use the artefact for a well-defined purpose.

As Pierce and Ball (2009) underlined, the knowledge of, the experience with and the views on, mathematics education and the role of technology within class activities guide the process of a teacher developing instrumental orchestrations. In particular, these often follow implicit guidelines, such as the teachers' own knowledge and skills concerning the integration of technology and their concerns about time constraints and behavioural control. These drive the teacher's choices and result in types of invariant teacher behaviour, which are instrumented by the available tools (Gueudet & Trouche, 2009). By promoting the creation of meanings through an orchestration process, the teacher can strongly stimulate the student's educational process (Lagrange et al., 2003).

In this paper, we use the term "orchestration" to refer to Trouche's idea of instrumental orchestration that, within the framework of the instrumental approach, points out the necessity for a given teacher to rely on external steering of the students' instrumental genesis. An instrumental orchestration is defined (Trouche, 2004) as the teacher's intentional and systematic organization and use of the various artefacts available in a learning environment in a given mathematical task situation, in order to guide the students' instrumental genesis. It is based on the combined action of three elements: "didactic configuration": arranging artefacts according to the teaching purposes fixed in advance; "exploitation mode": deciding on the roles that artefacts, teachers and students should play and choosing the technologies and procedures to develop as regards the didactic configuration; "didactic performance": assessing all the choices that a teacher should make during their implementation and envisaging possible inputs from students and any consequent choices to adopt.

METHODOLOGY

In order to answer our research question, we report and discuss results from three different studies all of which attempt to throw some light on the use of technology in math class activities. The first study (Study A) concerned teachers' perceptions of technology in math class. The second study (Study B) aimed at investigating how teachers orchestrate activities in a technology-rich class. The aim of the third study (Study C) was to analyse the relationship between work with manipulatives and technologically instrumented work within a laboratory approach.

In particular, it is important to underline that as far as the Study C concerns, we apparently moved toward a different level of investigation even though our interest from the point of view of this reflection is still related to the role of teachers and their professional development. As a matter of fact, we were also interested in figure out the crucial factors influencing teachers' choices (how, when and why) and how teachers can be helped to design, realise and evaluate the effectiveness of technology-rich activities.

FINDINGS FROM PREVIOUS RESEARCHES

As declared above, this paper reports and discusses results from three different studies, all of which attempt to throw some light on the use of technology in math class activities.

Study A, on teachers' perceptions of technology in math class

The aim of Study A was to understand how deeply math teachers do perceive the opportunities technologies can bring about for change in pedagogical practice, in order to effectively use them for the students' construction of mathematical meanings (Faggiano, 2009). Moreover, it aimed at verifying whether or not teachers realise that, in order to successfully deal with perturbation introduced by technologies, they have to keep continuously up-to-date and to acquire not only a specific knowledge about powerful tools, but also a new didactical and professional knowledge emerging from the deep changes in teaching, learning and epistemological phenomena. An anonymous questionnaire was submitted to 16 in-service high school teachers and 113 pre-service teachers. Key questions in the questionnaire included the following:

1. Do you think ICT could be useful for your teaching activities? Why?
2. Do you think that the use of ICT can somehow change the learning environment? And the way to teach? And the dynamics among actors in the teaching/learning situations?
3. Which difficulties do you think can be encountered when designing and developing a math lessons using somehow ICT?
4. As a teacher, do you think you need to have some didactical competences in order to properly use ICT? Eventually, which ones? And anyway, why?

Findings from the questionnaire revealed that in-service teachers perceived that technology can bring support to their teaching, but only inasmuch as it is a motivating tool enabling students to gain understanding per se. Answers given by the pre-service teachers were, instead, a little more didactically oriented: some of them recognise that, if nothing else, a knowledge of the instrument's functions is probably not enough for a teacher to use it in an effective way in terms of promoting construction of meanings by the students. An awareness of the opportunity to create a new "milieu" and change the "economy" of the solving process was totally lacking in the perception of the use of technology in mathematics teaching/learning activities, both of in-service and of pre-service teachers. As to the difficulties they think can be encountered when designing and developing a math lesson using technology somehow, they mostly ascribed possible difficulties to the lack of an adequate number of PCs and the technical problems that might occur, but also to the natural students' tendency to get distracted and to take a mental break, especially when facing a PC. As a consequence they did not feel the need to gain further technology skills for their teaching and did not usually consider that their lack of skills might present them with any difficulties. And, although 75% of the student teachers recognized the need to possess some didactical competences in order to use new technology, what they asked about was, in most cases, just software functionalities (not potential, nor constraints): only some of the pre-service teachers also asked to know how to effectively integrate their use in the teaching practice.

The process of a teacher developing instrumental orchestrations, therefore, has to be guided and, as highlighted by Pierce and Ball, a knowledge of, experience with and clear views on mathematics education and the role of technology within the class activities, are crucial needs.

Study B, on teachers training "in action": the case of Enza

The aim of Study B was to investigate how teachers orchestrate activities in a technology-rich class

(Faggiano et al., submitted). Some teachers with different experience and background have been videotaped and interviewed. Herein we focus on the case of Enza.

Enza is a secondary-school math teacher with a good knowledge of pedagogical content and with good skills in the use of technology. She decided to introduce, in her 9th grade class, the concept and properties of the circumference (in the plane), involving students in activities based on the use of the dynamic software GeoGebra. The topic, that can well be addressed with the chosen technology, offered the opportunity to verify the effectiveness of the experience, when bringing the matter up again after the school summer holidays.

In the overall experience, three different types of orchestrations could mainly be observed: starting from students' solutions to a task and guided by what happens when dealing with the task on the Interactive Whiteboard (IWB), Enza explained the mathematical content involved. Her orchestration often included a whole class discussion about what happens on the IWB, aiming to enhance the collective instrumental genesis; sometimes, especially in the last part of the experience, she brought to the fore an interesting answer among student's solutions and discussed it with the whole class. The "didactic configuration" allowed an obvious choice of the "exploitation mode" in which technology played a very important role. The roles played by each component of this "instrumental orchestration" clearly changed as the teaching activity developed, thus allowing the "observer" teacher to assess all the choices made during the implementation phase and to compare the students' input and their consequent choices to those established beforehand, in the "didactic performance" perspective.

It is noteworthy that although she observed that activities succeeded in bringing the lesson alive, when reflecting on the whole experience she concluded that the transfer of what students understood through the use of GeoGebra ("yes, I can see. It is clear") was problematic for conventional paper and pencil mathematics. Indeed, at the end of the experience students demonstrated that they had understood the concept and properties of the circumference, but, after the school summer holidays, they proved they had not fully dealt with the subject in the least. For this reason, Enza now says that she will repeat the experience in a new class, paying particular attention to this aspect:

> the introduction of the circumference and its properties can be done with the use of GeoGebra, discussing with the students their solution to some tasks, but it is extremely important to take care of the students' meaningful understanding. Technology is a means to achieve the discovery of a property, and to implement an interactive process in which students can have a voice, but knowledge thus obtained also needs to be transferred to the paper and pencil environment.

In conclusion, the described teacher training "in action" experience helped Enza to verify potentialities and constraints of her orchestrations and to focus on the opportunity to use technology within an integrated learning environment, in which a central aspect is the continuous alternation between technology and paper and pencil.

Study C, on technology-rich activities within a laboratory approach

The aim of Study C was to analyse the relationship between the work with manipulatives and the technologically instrumented work at primary school level (Faggiano, 2012). The research aimed at verifying if by manipulating both physical and technological instruments, within a laboratory approach, pupils can really achieve the building of new geometric concepts and a firm understanding of geometrical relationships. Herein we report a teaching experiment that has been conducted with 5th grade pupils: it integrates the technological opportunities offered by the Interactive Collection 123…Cabri (http://www.cabri.com/special-pages/bett2010/) within authentic learning situations, in which important steps have been based on the manipulation of physical objects such as paper, scissors, strings and straws.

Students worked mainly in pairs or small groups. Collective discussions aimed at exchanging ideas and find common solutions, as well as at comparing different strategies. Moments of individual reflection were finally dedicated to reflect on what was happening and culminated in the production of reports. The data collected included classroom observations notes, audio-recordings of lessons (transcribed), and other field notes. During each lesson, photographs were taken to provide information which could not be recorded by audio-recorder or field notes (for example, recording work presented on the blackboard).

During 3-hour afternoon meetings for a total of 30 hours within three months (from March to May), students were engaged in different kind of activities.

The first three meetings were devoted to creating a "classroom climate", breaking away from the usual "didactical contract" (in Brousseau's sense, 1997). The children were posed a series of challenges suited to their age. For instance, using the extremely attractive Tangram interactive activity of the collection "123...Cabri", diagrams were shown to be reproduced using the classical tangram seven pieces. From page to page the indicators to the solutions diminished from a multi coloured a black diagram without any indication to solving the problem. Students were then involved in reproducing themselves the tangram square, exploring the different pieces available and trying to use them for various creative productions. This crucial intuitive exploration and manipulation of the material contributed to highlighting in particular those properties of figures that relate to the dynamic nature of the position figures take up in the plane or to the different configurations of the borderline between tangram shapes in the composed figure, thus leading to the enrichment of the geometric vocabulary.

Further meetings concerned the characteristics and classification of triangles and quadrilaterals. Pupils were firstly asked to construct triangles and quadrilaterals using pieces of straws (with different length) and a string. They realised that it is not always possible to obtain a triangle while with four pieces of straw it is possible to construct "more than one" quadrilateral. Then, using some paperweight, students focused their attention to the diagonals of the quadrilateral. Discussion leaded to the use of ruler, paper and scissors in order to make lots of different quadrilaterals to be drawn on their exercise book. Geometrical intuition had at this time a crucial role. With the aim to overcame the difficulties learners have with coming to an understanding of the hierarchical relationship between quadrilaterals further activities were carried out. In particular, pupils interacted with some of the activities of the collection "123...Cabri" which have been designed with the aim to focus on the properties of the figure by means of an adequate selection of tools and of the "drag-mode".

Analysis of the results revealed that while working on learning activities in an integrated laboratory approach the students gained some insight into the structure of plane geometry, thus fostering not only the building of new geometric concepts but also a firm understanding of geometrical relationships. Moving from the physical object that can be manipulated to the geometrical drawing (by identifying features) and from the drawing to the geometrical object (by means of dynamic environment activities and of interpretations of the feedbacks thus obtained) can show how the use of manipulatives, graphic activities and gradual refinements are all consequences and sources of learning.

According to the research results, it can be claimed that within an integrated laboratory approach, making hypotheses about the relationships between geometrical objects, manipulating and constructing the objects for themselves, and verifying the truth of their conjectures in various ways, students may develop not only a change in their geometrical work but also, in a spiral and iterative fashion, a feeling for the need of proof of any explanation which will be very important in their further math education. From this point of view, well designed authentic learning activities (using both physical and technological instruments) can offer opportunities for a progressive geometric mathematization.

CONCLUSIONS AND FUTURE DEVELOPMENTS

In conclusion, reconsidering findings arisen from the three studies, we deem that the crucial factors influencing the awkward process of integrating technology in math class are: the teacher's knowledge of pedagogical content related to the use of technology; the decisions the teacher takes in determining when integrating technology in everyday teaching practice and how to structure the learning environment; the choices s/he makes when facing the problems that new environments require a new set of mathematical problems, that both the constraints and potentialities of the artefacts need to be understood and that the instrumentation process and its variability needs to be managed.

In particular, the studies we described above have strengthened our conviction that an awareness of the potential and limitations of technology in the teaching field, as well as a knowledge of the related pedagogical content, are essential conditions to ensure an adequate orchestration of the teaching activities. It is highly important, therefore, for the teacher to be able to review the teaching activities s/he has conducted and reflect on what happened in class. To do this, proper tools emerging both from teaching practice and from research findings are a fundamental requirement. These will allow the teacher to refine her/his pedagogical content knowledge and improve subsequent steps in the process. Clearly, for the teacher this is a long, complex undertaking that is both demanding and time-consuming. For this reason, it will probably take quite a few years to bridge the gap between the planned curriculum and those implemented.

Our plan here is to start from the positive results obtained in previous studies, using them as a springboard for developing a long term teacher training "in action" project with some in-service teachers, in order to promote the integration of technology in their teaching practice, and to assess the impact and results. In parallel, we aim to continue to work with pre-service teachers, giving them the chance to be the subject of a "mise en situation". That is, we aim to allow teachers to be an active part of a learning situation, engaging them to solve unusual problems which require non-standard strategies. In this way, teachers can experience for themselves the difficulties students may encounter, the cognitive processes that they can apply, and the attainments they can achieve. They will also have the opportunity to understand and manage students' instrumental genesis and to become more skilful and self-confident when deciding to exploit the potential of software in mathematics education. In particular, we aim to verify whether the "mise en situation" experiences could allow teachers to become more aware of the important relationship between the specific knowledge to be acquired by the students and the knowledge possessed by the teacher, as well as between the specific knowledge to be acquired by the students and their prior knowledge.

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