DIGITAL TECHNOLOGIES IN MATHEMATICS CLASSROOMS: BARRIERS, LESSONS AND FOCUS ON TEACHERS

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In this paper, drawing from data from several experiences and studies in which I have been involved in Mexico, I reflect on the constraints and inertia of classroom cultures, and the barriers to successful, meaningful and transformative technology integration in mathematics classroom. I focus on teachers as key players for this integration, calling for more teacher involvement in both professional development, and as co-constructors and collaborators in the design of technological implementations and resources.

Keywords: Technology, Teacher Education-In Service/Professional Development

Classroom Cultures, Teachers and Technologies

Throughout his career, Seymour Papert, a pioneer advocate of digital technologies for changing learning, criticized the way in which school systems constrain knowledge and learning. At the ICMI Study 17 study conference in 2006, in the final talk of his life (Papert, 2006), Papert denounced that educational systems ration every aspect by dividing learning into school grades, "cutting up the knowledge into the subjects" and ordering it; with schools being dictated by graphocentrism—i.e. by paper-and-pencil technology—and new technologies being used only to implement what was there before the newer technologies. He ridiculed that situation by saying: "We'd never have had airplanes...if we had constrained the new transportation to follow the schedules of the sailboats and the horse-drawn carriages; but that's what we are doing in our schools" (Papert, 2006).

Before delving into the issues of the constraints—or what I call the inertia—of educational systems, let us look at some evidence on how digital technologies and tools (DT) have been used and are being used in schools, using data from several studies carried out in Mexico over a decade, and from the research literature.

Uses of Digital Technologies in Classrooms in Mexico and Elsewhere

In a survey carried out in Latin-America in 2006 and reported in Julie et al. (2010), it was found that the most predominantly-used software in mathematics classrooms were software for word processing (Word, LaTex, PDF) and presentation (PowerPoint) – not mathematical tools, but communication ones. Other studies in Mexico at middle-school (Rodríguez-Vidal & Sacristán, 2011) and high-school levels (Miranda & Sacristán, 2012, 2016) showed similar results, with few teachers using technology in classrooms, and of those who did, for simply presenting information, projecting videos, plotting graphs or checking results produced in paper-and-pencil, with very rare use of technology by students. In those studies, the access to technology in classrooms was scarce.

Despite technology becoming more accessible in some schools, this year (2017), Luc Trouche and I visited a high-school in Mexico where we again observed a teacher using technology in a similar way: to simply project static function graphs using GeoGebra, completely omitting any of the dynamic and experimental possibilities (and main purposes) of such a "Dynamic" Geometry environments (DGEs). (In Sacristán, 2011, we also reported on a case where the teacher failed to transmit the dynamic function of a DGE, and students simply used the software for drawing static figures.) Furthermore, the 2017 teacher did not encourage—in fact, *dis*couraged—students from using technological tools in the classroom (interestingly, however, a couple of students ignored the teacher's recommendations, and did use a tablet to reproduce some of the functions demonstrated by

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the teacher).

Although in more developed countries, technological tools in the classrooms are becoming increasingly ubiquitous, the use of DT is not so different. For example, in the UK, a report edited by Clark-Wilson, Oldknow and Sutherland (2011), cites other reports that conclude that, despite considerable investment in DT in schools, these are underused within in secondary mathematics classrooms and, if used, their potential is generally underexploited. The report also points to classroom evidence suggesting that the use of DT has had emphasis

> on teacher-led use, using mainly presentational software such as PowerPoint and interactive whiteboard software. Revision software and online content services are also used, with the focus being on the computer teaching mathematics alongside practice exercises. Where digital mathematical tools such as graphing calculators, dynamic geometry, and spreadsheets are used, these are conceived primarily as presentational, visual and computational aids rather than as instruments to facilitate mathematical thinking and reasoning. (Clark-Wilson, Oldknow and Sutherland, 2011, p. 19)

On his part, Trouche (2016), while pointing to a lack of research at a large-scale for analyzing the real integration of technology in mathematics classrooms, reports that, in general, integration remains local with a huge difference between schools and teachers. It is also mostly teacher-centered (at least in the cases of England and France), with sometimes teachers showing students the use of the technology, or being unable to analyze the effects of the technology being used. Monaghan hypothesizes that, in the case of England, the increased teacher-centered use of DT in class in classrooms could be due to the increase of interactive whiteboards (IWBs) with "a very large proportion of the use of IWBs is teacher use of IWBs with PowerPoint (rather than interactive mathematics software) and the result is 'teacher demonstration,'" perhaps pointing to students "not being granted wide access to tools to explore mathematical relationships" (Monaghan, Trouche & Borwein, 2016, p. 388). I argue that teacher demonstration is due also to the inertia of old school practices and cultures that are teacher-centered, particularly in countries where this model is still prevalent, such as Mexico.

I summarized these observed predominant uses in classrooms of technology in Sacristán (2011; in press), as being for:

- Presentation or demonstration (e.g. PowerPoint, projecting graphs, videos, etc.)
- Easier visualization
- Easier, faster computation and accuracy
- Saving time (time optimization)
- Checking paper-and-pencil task results
- Information
- Student's revision, exercises or "drill and practice" through interactive, or online resources (such as pointed by Clark-Wilson, Oldknow & Sutherland, 2011, above)
- Communication (e.g. using email or Internet for sending homework)

With many times:

- Little innovation (doing, as Papert criticized, the same or similar tasks as with paper-and-pencil)
- A lack a sense or understanding of didactical and mathematical purposes for the use of digital tools in their classrooms; leading to technocentrism (showing or teaching about the tool itself—see Brennan, 2015—rather than using the tool for mathematical purposes)

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- Ignoring the purpose or potential of the tools (e.g. no dragging or dynamism using DGE, as narrated above), indicating, again, the influence of graphocentrism
- Unlinked to other resources (Monaghan & Trouche, 2017)

Thus, when we look at the evidence of how digital technologies are used in schools, we see that in fact they are used in the direction that Papert (2006) claimed: to teach and serve the old (e.g. serve existing curricula), with much of their potential ignored.

On the other hand, the research literature is full of successful innovative practices with technology at experimental scale. But many authors, and at different education levels (see also, Clark-Wilson, Oldknow & Sutherland, 2011; Artigue, 2012), point to how

> despite over 20 years of research and curriculum development concerning the use of technology in mathematics classrooms, there has been relatively little impact on students' experiences of learning mathematics in the transformative way that was initially anticipated. (Clark-Wilson, Robutti & Sinclair, 2014, p.1)

In Sacristán (in press), I reflected on the gap between research results and what happens in classroom practices. Clark-Wilson, Robutti & Sinclair (2014) indicate that a response to this has been increasing research on the role of the teacher; and that will be the theme of the last section of this paper. But I will focus now on the reasons, such as different types of obstacles and barriers, impeding more meaningful technology integration in schools and practice.

Difficulties and Challenges for the Integration of DT for Math Learning in Classrooms

Between 1997 and 2006, a government-sponsored national program in Mexico called EMAT (Teaching Mathematics with Technology) was put into practice for gradual implementation of expressive computational tools, together with a pedagogical model, in the middle-school mathematics classrooms (see Sacristán & Rojano, 2009). We learned a lot from that program in terms of issues that emerge when attempting large-scale massive implementation of technologies in schools (even when carefully designed and planned through the expertise of an international team of mathematics education researchers, as was EMAT). Difficulties and obstacles were encountered at different levels: (a) the teacher, student and classroom level; (b) the school level; (c) the local authorities level; and (d) the national government level; and of different kinds related to:

- *changes in classrooms practices and cultures*: both teachers and students were unaccustomed to working in a more exploratory, student-centered, setting, and teachers had difficulties in adapting to the *proposed* pedagogical model
- *integration of technological tasks with the established curriculum*
- *time issues*: time (or lack of) for preparing the technology-based tasks, and for their implementation
- (teachers') *content knowledge of mathematics*: the use of technology made teachers aware of their deficiencies of their mathematical content knowledge, leading to two types of consequences: (i) some teachers did not want to continue working with technology; or (ii) in other cases, it *motivated* and helped teachers improve their content knowledge.
- *professional development* and support in terms of the tools – which was usually insufficient and without *continuity*
- *teachers and students' attitudes, beliefs and confidence* with regards to the use of the technological tools and programs: these have been shown to have an impact on students' learning with the tools (Sacristán, 2005). As we put it in Sacristán and Rojano (2009, p.213): "Putting it bluntly, 'good teachers' achieve good results: they are able to take

advantage of the *technological* tools and their students benefit from those experiences; but less experienced, poorly trained teachers, or simply teachers who dislike the technological tools, do not do so well."

- *technical difficulties*
- *administrative and bureaucratic issues, policies and political issues*, including lack of communication between the different levels of authorities. It is also worth noting that the program was discontinued in 2006 due simply to a change in government (change in policy). It did survive at some local levels, mainly in places where there would be some form of local support, such as a self-appointed regional coordinator.

In other studies (e.g. Sacristán, Sandoval & Gil, 2011; Miranda & Sacristán, 2016), there were similar findings pointing to reasons that impede the integration by teachers of DT. Among these: difficulties in accepting changes (even when they recognize possible benefits of DT) with many of them continuing doing the same as before; fears (e.g. of losing control of the class, of showing mathematical and technical deficiencies); difficulties in understanding how to integrate technologies in terms of the mathematical aims; lack of adequate infrastructure; and lack of time.

These difficulties are similar to those mentioned in the BECTA (2004) review on barriers to the uptake of information and communication technologies (ICT) by teachers. That report categorizes barriers (e.g. lack of access to resources—including lack of hardware, inappropriate organization, poor quality software—lack of time, lack of effective training, technical problems, lack of confidence, resistance to change and negative attitudes, no perception of benefits) into school-level barriers and teacher-level barriers, which can be external and internal barriers. Likewise, Clark-Wilson, Oldknow and Sutherland (2011, p. 20), cite a report from the UK's National Centre for Excellence in Teaching Mathematics where mathematics teachers' concerns about the use of DT are listed as related to:

- a lack of confidence with digital technologies;
- fears about resolving problems with the technology;
- fears about knowing less than their learners;
- access to digital technologies;
- inappropriate training;
- lack of time for preparation;
- a lack of awareness of how technology might support learning;
- not having technology use clearly embedded into schemes of work,

and include among the barriers to the more student-centered use of DT:

- an inadequate guidance concerning the use of technological tools in curriculum documentation;
- assessment practices;
- and "a perception that digital technologies are an add-on to doing and learning mathematics".

To these we can add the current overload of information and availability of resources of varying quality that are available to teachers through the Internet.

From Challenges to Trends and Lessons

The *NMC Horizon Reports* (www.nmc.org) takes a look every year (since 2012) at technology adoption, at both K-12 and higher education, enlisting (six for each) (i) key trends accelerating

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technology adoption, (ii) significant challenges impeding technology adoption, and (iii) developments in technology, poised to impact teaching, learning, and creative inquiry.

Among the trends that are identified in several of the reports (Johnson et al., 2015; Adams Becker et al., 2017; NMC/CoSN, 2017) that will be having an impact—in the short, mid and long terms—on technology adoption, are: an increasing use of collaborative learning approaches and of blended learning; a shift from students as consumers to creators and the recent push for coding literacy; the rise of STEAM learning, which seeks to engage students in interdisciplinary learning breaking down traditional barriers between different classes and subjects—one of the criticisms raised by Papert (2006), cited at the beginning of this paper; a rethinking of how schools work, shifting to deeper learning approaches (e.g. project-based learning, etc.) and a redesigning of learning spaces.

At the same time, one of the challenges that the *NMC Horizon Reports* consider difficult (even "wicked" at higher education level), is the changing role of teachers and educators, whose

> primary responsibilities are shifting from providing expert-level knowledge to constructing learning environments that help students gain 21st century skills including creative inquiry … acting as guides and mentors, … providing opportunities for students to direct their own learning trajectories. (NMC/CoSN, 2017, p. 7)

The nine years of EMAT led us to identify some of the key factors for success and for transforming school practices and teacher's roles, such as: adequate planning, gradual implementation, continuous professional development and support, and enough time (years) for assimilation and integration (Sacristán & Rojano, 2009). In relation to the latter, we found that even the most enthusiastic, committed towards the program, and supported teachers, needed at least three years in order to appropriate themselves of the tools and pedagogical ideas. But those who did became very successful in the future, continuing using the resources from the program for many years on their own, even until even this day. In fact, during the writing of this paper, I received an out-of-the-blue call from one of the teachers with whom I worked during the EMAT program. She told me of the limited resources in the school where she now works, in a very low-income area, but how, by implementing the EMAT materials in the last few years (more than a decade after they were developed), student achievement and assessments had improved dramatically, and she had even won two prizes for her work (one of them for her students' explorations with Logo of the four-color theorem). This case shows an appropriation by the teacher of the resources, tools and pedagogical ideas.

It is thus clear that the key player for successful implementations of technology-centered educational innovations is the teacher.

> the role of the teacher is very important, and his/her beliefs, insecurities and lack of mathematical and technical preparation affect the possible impact that the use in the classroom of these technologies can have on students' learning and even attitudes. The need for careful, considered and continuous work with teachers is thus extremely important. A priority in this kind of work should be the integration of digital technologies with the work that teachers are required to do, to take them into account at all steps of the implementation process, and to assist them in developing pedagogical strategies. (Julie et al., 2010, p.380)

With respect to the latter, I would like to reflect briefly on policy aspects and the changing role of teachers in the design of technological implementations.

A Reflection on Policies for Technology Integration, Societal Changes and Teachers

The EMAT program was a top-down design: a policy-driven decision that attempted to achieve technology integration in mathematics teaching and learning, and teachers were not involved in its design. It may have succeeded in small scales, but for an innovative educational program to catch on, it cannot be only about policy-driven implementations, no matter how carefully and well designed it is. For appropriation by teachers of new resources and pedagogical ideas, it may be a prerequisite to involve teachers in the design from the beginning, not just as participants, but as co-creators. In fact, rather than a technologically-driven model of technology integration, Hennessy, Ruthven, and Brindley (2005) point to the importance of teacher involvement, although also influenced by the teachers' working contexts, for effecting classroom change. Furthermore,

> approaches with the most potential to bring about genuine improvement in learning mathematics are those that resonate with teachers—with their interests, beliefs, emotions, knowledge, and practice. (Kieran, Krainer, & Shaughnessy, 2013, p. 364)

But involving and engaging teachers in the design of technological implementations is only one part of what is needed. There are dialectical forces at play here. On the one-hand, top-down policies do generate part of the change: they can initiate it and sow seeds of transformation (as in the case of teachers from EMAT, who 15 years later, continue working and transforming classrooms with what they learned); even if, as an imposition, it is unlikely it will resonate with the majority of teachers. On the other hand, changes that take place in society due, for instance, to technological advances—such as the trends mentioned in the NMC reports above—also influence policies. In any case, professional development and support is needed. In Trouche, Drijvers, Gueudet, and Sacristán (2013), we discussed the above and said:

> Merely providing access to technology is not enough for promoting educational change; support for teachers' professional development is a necessary precondition for a thoughtful and fruitful integration of technology. […] Policy shifts do not fall out of the blue, but reflect or intend to support underlying views on learning, and are mediated by new paradigms of teaching and learning. (Trouche et al., 2013, p. 756)

The issue of professional development was also touched upon in the NMC reports, in relation to the changing role of teachers:

> The evolving expectations also change the ways teachers engage in their own continuing professional development, much of which involves social media, collaboration with other educators both inside and outside their schools, and online tools and resources. Pre-service teacher training programs are also challenged to equip educators with digital competencies amid other professional requirements (NMC/CoSN, 2017, p. 7)

I will now focus on teachers as the core of the efforts for improving meaningful technology-integration and promoting changes in classroom cultures.

Improving Technology Integration in Math Classrooms: Focus on Teachers

Based on what was said in the previous sections, this focus on teachers has two aspects: (i) professional development, and (ii) enhancing teachers' involvement in generating changes, resources and decision-making.

I will begin by drawing from two experiences of in-service professional development programs of which I was part of, both of which emphasized self-reflection by teachers.

Two Experiences of Reflective Professional Development Programs for In-Service Teachers

As the EMAT experience taught us, there is a need to strengthen the mathematical content knowledge of teachers in our country, so the training and self-reflection processes in both programs addressed three aspects: the technological, mathematical and pedagogical.

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Experience 1. From 2005-2010, I participated in a long-term professional development program for a small group of six in-service teachers in Mexico. As described in Sacristán, Sandoval and Gil (2011), our approach was for teachers to reflect on the changes in their practice through both training and classroom implementation of DT, document their findings and present them in seminar sessions to their fellow participants and the tutors. For this, we developed a professional development model (Fig. 1), based on works (e.g. Artzt and Armour-Thomas, 1999) that provide models in which teachers reflect on their instructional practice. In the pedagogical design of our model, we considered teaching as a constructive process that requires reorganizing and reinterpreting the subject matter and the practice as a result of experience (Thompson, 1992); and that the knowledge that is derived from social interactions in a (real-life) context is more valuable and significant for the teacher (Liu & Huang, 2005).

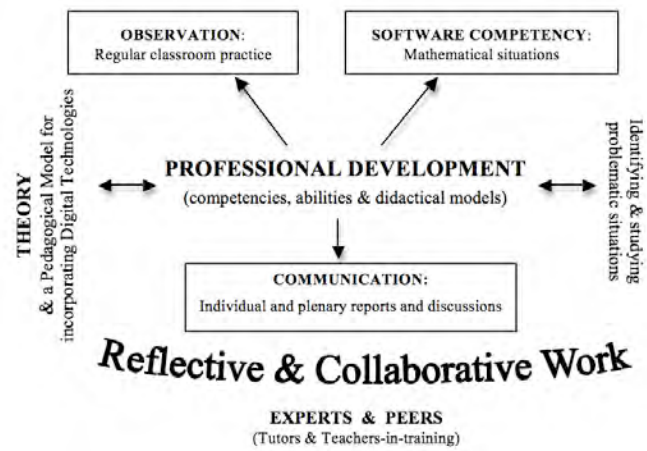

Figure 1. The professional development model described by Sacristán, Sandoval & Gil (2011).

In our program, teachers were involved in: (a) training and development of abilities, for the use of DT in the classroom (mainly Spreadsheets, Dynamic Geometry, CAS and Logo, as well as some applets); (b) the design and planning of teaching strategies and activities that integrate DT; and (c) engaging in observation and reflection-on-action (Bjuland, 2004) of the changes in their own teaching practice with the new tools. The participants also studied and discussed theoretical frameworks and pedagogical models for a meaningful incorporation of DT into the (mathematics) classroom. In parallel, the participants attempted to incorporate DT, as well as the pedagogical models studied, into their real-life classroom activities, analyzing and reflecting upon the potentials, limitations and changes brought forth by this incorporation of DT into their own practice, and that of their colleagues, from various perspectives. These activities and model are schematized in Figure 1. This experience, even though it was a top-down initiative, gave the participants the opportunity to reflect upon and share their personal experiences with the other participants. We consider that the diverse elements of the development model—training, continuous support, processes of reflection, self-observation, and promoting equally the technological, mathematical and pedagogical aspects—were significant for helping generate changes in the participants' professional practices, and enabled them to construct didactic strategies for the use of DT, more in accordance with the specific needs of their students and/or of other teachers. Half of them even appropriated themselves of our model's ideas, for peer training, designing and implementing a training program for other teachers and colleagues.

All six participants considered the educational system as very rooted in traditional ways and difficult to change; but they perceived a change from a technical and presentation use of DT, to more mathematically-centered uses, both in themselves, and in some of those they trained.

Experience 2. In 2009-2011, as described in Parada, Sacristán & Pluvinage (2013), we used a theoretical and methodological model called the Reflection-and-Action (R-&-A) Model, for promoting reflective processes—as a complement to professional development, and for strengthening the teachers' mathematical content knowledge—in two communities of practice (CoP) of mathematics educators (in-service teachers and researchers) in Mexico: one with 46 members; another with 125 members, which met through internet forums and periodically in person. The R-&-A model centered on a mathematical activity that was reflected upon before, during and after a teaching experience, i.e., through three reflective processes: (a) reflection-for-action; (b) reflection-in-action; and (c) reflection-on-the-action. The reflections that emerged enhanced teachers' mathematical content knowledge related to the specific activities, and also helped them recognize the need to adapt methodological and didactic resources, such as DT, to the purposes and characteristics of each student group.

Teachers as Active Collaborators in Meaningful Technology Integration

In the above section, I presented professional development experiences that promote teacher reflections and collaborations. The first one, though successful, was not a teacher initiative. The second one, included a researcher as mediator who proposed and coordinated the mathematical reflective processes. I believe that in order to generate change, teacher involvement and collaboration with researchers needs to take place in a way that makes teachers feel they are decision-makers. I consider this crucial in terms of motivation, beliefs, and overcoming affective apprehensions – which we have seen are areas that can be important barriers to integration and sustainability. Sustainable CoPs or networks involving both researchers and teachers are important and ICT makes it possible to share, discuss and remix resources online. A useful example from which we can draw lessons, is that of Sésamath (http://www.sesamath.net/) in France (see Trouche et al., 2013), which emerged as a bottom-up approach where mathematics teachers started to share and design resources and software. A bit over ten years ago Sésamath started to collaborate with researchers (Trouche et al., 2013). The quality of the resources at the beginning may not have been so good but through the sharing between teachers, and collaboration with researchers, these were greatly improved (Monaghan & Trouche, 2017).

> Explaining the reasons for the success of *Sesamath* requires specific research. The existence in France of the IREMs (Institutes for Research on Mathematics Education), a national network that involves many mathematics teachers, has played an important role. A similar project could perhaps not succeed in countries were such a network, linked with mathematics education, did not exist. (Trouche et al., 2013, p.772)

Concluding Remarks

In this paper I began by quoting Papert (2006) and his criticism of educational systems as a way of introducing the issue of the difficulties of creating meaningful change and technology-integration in classrooms, and the inertia of the classroom and the paper-and-pencil cultures that limit change. This was then expanded in listing some of the barriers identified from decades of research, to that change and integration. After a brief excursion into some of the lessons learned from technological and educational trends, I focused on the teacher as the key player for successful and transformative technology-integration and argued in favor of promoting models of collaboration (such as CoPs and networks) between teachers, researchers and policy-makers that both enhance teachers' professional development, empower them and provide a means for sharing, discussing and improving resources and their implementations, as well as overcoming some of the detected barriers. But one of those barriers is time: educational systems need also change (perhaps pushed by the trends of society) in a way that makes them more flexible for allowing teachers more time to engage in collaboration and innovation.

There are some other aspects that I did not cover in this paper, and that are worth reflecting upon. For instance, what role do MOOCs have, or will have, both in terms of changing the role of teachers and of technology for teaching and learning mathematics; as well as for teachers' professional development? Or are they a way of up-scaling current educational practices without truly innovating them?

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