TECHNOLOGY INTEGRATION BY PRIMARY-SCHOOL TEACHERS IN RURAL MEXICO AND THE DESIGN OF A PROFESSIONAL DEVELOPMENT PROGRAMME

Ana Isabel Sacristán & Homero Enríquez-Ramírez

Cinvestav-IPN, Mexico; asacrist@cinvestav.mx, homero.enriquez@cinvestav.mx

In this paper we describe parts of a (pre-pandemic) research where we investigated the access and use of DT for mathematics by primary school teachers in a rural region of Mexico, in order to design a professional development (PD) course for such teachers. The research included: First, a diagnostic phase to investigate teachers' previous training in the use of DT and their access to these resources. Then, a design-based study where we designed, implemented and refined a PD course for integrating DT in the teaching of mathematics. Concurrently, we examined some of the participating teachers' uses of DT. We describe here some of the results from that research, which show the difficulties in access that such teachers face, how they orchestrated the DT available for mathematics lessons, and the need for teacher training that takes into account their context, reality and possibilities.

Keywords: Technology-use in developing countries, primary-school education, instrumental orchestration, teacher training

INTRODUCTION AND THEORETICAL FRAMEWORK

In developing countries, such as Mexico, there is a digital gap, that needs to be addressed (Sunkel et al., 2014), and schools are ideal spaces for this purpose (Peres & Hilbert, 2009). In fact, the integration of digital (DT) resources to the teaching of mathematics is a social and pedagogical necessity (Sunkel et al., 2014). However, deficiencies have been observed in that regard in sectors of the Mexican primary education system. In Mexico, and more so in rural areas, the use of digital technologies (DT) in schools, particularly in state primary-schools, is scarce. One problem is the lack of hardware and software. In fact, in 2021, it was found that less than 45% of Mexican homes had a computer (INEGI, 2022), with most people relying on their mobile phones for connectivity (e.g., WhatsApp, which became how most teachers and students communicated during the COVID pandemic), and only around 50% of people used the Internet in rural areas (INEGI/SCT/IFT, 2021).

Another problem, is that teachers lack professional development (PD) for the integration of DT to their teaching practice, and particularly in terms of its didactical use: in fact, as could be seen in the syllabus of the official teacher training programs (SEP, 2018), DTs were given very little importance in primary-school teacher training.

Moreover, in the past fifteen years, there have been few succesful initiatives for DT integration in Mexican state schools. The last significant programmes by the Ministry of Education, were in the early to mid 2000s –the Enciclomedia programme for primary education, where schools were equipped with computers and smartboards, and interactive apps accompanied the official textbooks; and the EMAT (Teaching Mathematics with Technology) programme that introduced, among other tools, Spreadsheets, Dynamic Geometry and Logo programming for mathematics in middle-school education (see Sacristán & Rojano, 2009; and Trouche et al., 2012). But after 2006, DT in state schools, and the training of teachers on their pedagogical use (such as for the teaching of mathematics), became very limited or non-existent.

In this paper we describe parts of a (pre-pandemic) research where we investigated the access and use of DT for mathematics by primary school teachers in a rural region of Oaxaca, Mexico, in order to design a professional development (PD) course for such teachers. The research included: First, a diagnostic phase to investigate teachers' previous training in the use of DT and their access to these resources. Then, a design-based study where we designed, implemented and refined a PD course for integrating DT in the teaching of mathematics. Concurrently, we examined some of the participating teachers' uses of DT. For that analysis, several theoretical approaches were used: that of Instrumental Orchestration (IO) (Drijvers et al., 2010); Hughes's (2005) categories on technology use; and, for examining the changes in teachers' participating in the PD courses, the Documentational Approach to Didactics (DAD) (Gueudet & Trouche, 2012).

The IO was used to analyze the way in which teachers organized and used digital resources in their mathematics classes. In particular, we examined teachers' IOs by analyzing their didactic configuration of the existing artifacts and their arrangement in the teaching environment; the expected method of exploitation of said artifacts; and the didactic performance of the teacher in the class using the planned technology. For this, we relied on the six ways of orchestrating technology identified by Drijvers et al. (2010) –technical-demonstration, explain-the-screen, link-screen-blackboard, discuss-the-screen, detect-and-show, and sherpa-at-work– and also identified other orchestrations.

Hughes' approach (2005) identifies three types of technology use: (i) as a replacement (without changes in the way of teaching, promoting the same learning processes and goals) ; (ii) as an amplifier (class tasks are carried out more efficiently and effectively, even though they are the same); and (iii) as transformative (changes are made in teaching practices, in student learning routines, and in the roles of teacher and students).

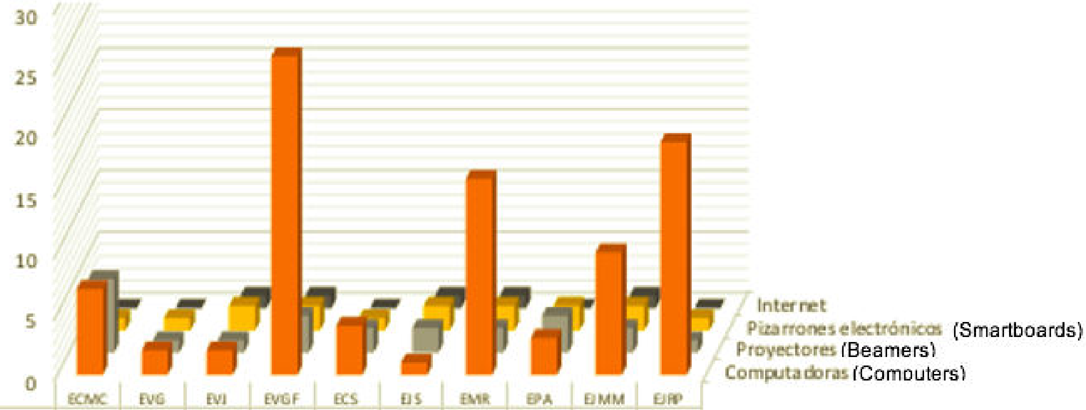
The DAD studies teachers' practice and their professional development by looking at their interaction with the resources they use (select, adapt, review, reorganize) for teaching mathematics, which is called a documentation work (Gueudet & Trouche, 2012). This work produces documents, which are composed of recombined resources and the usage schemes associated with them; a teacher's set of documents is their documentation system (DS). Throughout a teacher's professional career, their DS evolves as they work and experiment with old and new resources. Thus, the teacher's documentation work reveals their professional development, that is, the evolution of their practice, knowledge and beliefs (Gueudet & Trouche, 2012).

THE FIRST PHASE: IDENTIFYING ACCESS AND USE OF DT

In the diagnostic phase of our study, in 2017, we explored the access and use of digital technologies (DT) for the teaching of mathematics by primary school teachers in the region of our research. In 10 schools of that region, we interviewed each school principal, and 67 teachers answered a survey, in order to inquire on the availability and use of DT resources, as well as teachers' perceptions of their potential for mathematics learning. We then observed some of the lessons of ten teachers who had stated in the survey that they did use DT to teach mathematics, and interviewed those teachers.

We classified the results in terms of three categories: (i) Access to DT (both in schools and in teachers' homes); (ii) Perceptions of teachers and principals on the use of DT for the teaching of mathematics; (iii) DT use for mathematics teaching. This information was considered, in the later intervention phase, for the design of the PD course aimed at promoting the integration of DT for mathematics teaching.

In terms of access, most schools lacked hardware; there was old, mostly abandoned, Enciclomedia hardware from 2005-06 that was present in most schools. The ratio of students per computer ranged from 11.5/1 at one extreme, to 170/1 at the other. Internet access was limited (of the five schools where Internet access existed of them it was of very poor quality and two of the other schools lacked the equipment to take advantage of it. Added to that, school policies limited the use of what little is available. Thus, DT access was limited (see Fig. 1).



	ECMC	EVG	EVI	EVGF	ECS	EIS	EMR	EPA	EIMM	EIRP
Computadoras	7	2	2	26	4	1	16	3	10	19
Proyectores	6	1	1	3	2	2	2	3	2	1
Pizarrones electrónicos	1	1	2	2	1	2	2	2	2	1
Internet	0	0	1	1	0	1	1	0	1	0

Figure 1. Available DT hardware in the observed schools.

In terms of teachers' perceptions, DTs were seen as something positive that they would use "if they had them" and "had the knowledge to use them". Most participating teachers were unaware of the potential of DTs for mathematics. In fact, the majority of the teachers, had little previous training in the use of DT for teaching mathematics: only 25% had taken courses related to the use of technology, although many were mostly technical and did not focus on its didactic use.

Thus, their use of DT in their practice was scarce, and inconsistent. However, some teachers tried to do their best with what was available. Through the survey we found that, for mathematics, 21% (14) said they never used it, 24% (16) rarely, 44% (29) occasionally and 11% (7) almost always. When asked in the survey about the type of resources they had used for mathematics and the activities carried out with them, 61% (41) of the teachers answered. Of these, 32% (13) indicated that they used videos to support their explanations of a topic (e.g., to explain procedures); 34% (14) used beamers to project images, problems or exercises; another 34% (14) used interactive apps (e.g., apps from Enciclomedia or others, such as for addition and substraction); 24% (10) printed materials for the class downloaded from the Internet (e.g., riddles, problems, geometric drawings); and two teachers (5%) mentioned having used the calculator.

Class observations allowed us to examine further the ways in which these teachers used and orchestrated the digital resources (videos, projected information, interactive apps, printed material and calculators) in their mathematics classes. We present information from nine of the ten observed teachers, whom we called (using pseudonyms): Armando (Ar), Alicia (Al), Alfredo (Alf), Paola (P), Carmelo (Ca), Cecilia (Ce), Rosi (R), Alexa (Alx), and Hortensia (H). Table 1 summarizes the type of orchestrations that we identified for each of the resources, as well as the types of uses based on Hughes's (2005) categories. A detailed analysis of the orchestrations of two of the teachers is presented in Enríquez and Sacristán (2019).

Resource	Teachers	Observed IOs	Types of uses
Video	Ar, Al, Ce, H	Explain-the-topic; explain-the-screen; repeat-the-screen	Replacement & Amplifier
Projected information	R, Alx, H, Ca	Copy-the-screen; discuss-the-screen	Replacement & Transformative
Interactive app	Alf, Ca, H	Technical-demonstration; explain-the-screen; Sherpa-at-work	Amplifier
Calculator	Ca	Detect-and-show	Amplifier/ Transformative
Printed material	P	-	-

Table 1. Orchestration and types of use of the digital resources used by teachers.

Five teachers (Ar, Al, Alf, Ca, Ce) used a laptop and a beamer; three (R, Alx, H) took their students to a computer room (with one or two children per computer); and one (Ca) provided calculators to each student. We observed the use of videos in four cases: three of them (Ar, Ce and H) orchestrated it in the Explain-the-topic mode, using it to provide an explanation of the topic, either to remind students of a concept already seen (e.g., angles –H's case); present a new one (e.g., mean, median and mode –Ar's case); to identify procedures (obtaining mean, median and mode –Ar's case; conversions from fraction to percentages –Ce's case). Other ways of orchestrating the video were Explain-the-screen and Repeat-the-screen: for example, teacher Al would stop the video to explain a part of it again, and then carry out with the children an activity suggested in the video (make the largest or smallest amount possible given four figures on cards). These orchestrations show a use of technology as a replacement and amplifier, since it was used to replace and/or expand the teacher's explanation, with illustrations and animations to optimize the activity.

In the survey, 34% of teachers used beamers to project information (eg, a document or a web page). Four of observed teachers used this in class: in three cases (R, Alx and Ar), the orchestration was Copy-the-screen, carried out in a computer lab: the children copied the information shown on the computer screen (e.g., representations of fractions, angles) into their notebooks –we considered this use of DT as a replacement. Four other teachers used the projection to pose a problem (with response options); in the case of Ca, children, with the help of the calculator, found and discussed the solutions. We considered this mode of orchestration as Discuss-the-screen: using DT to validate, compare and experiment, activities that could be considered as transformative (Sandoval, 2017).

The use of interactive apps was pointed out by 34% of the teachers. In two of the observed cases (Alf & Ca) these resources were orchestrated as: Technical-demonstration, where students were given guidance on the use of the equipment; as Explain-the-screen where how the app worked was shown; and in Sherpa-at-work mode, where some kids led their teams and used the apps. In Alf and Ca's orchestrations, there was also an amplifying use of technology: in both cases, mental calculation exercises were encouraged together with the interactive apps use in order to promote the attention and participation of the children.

The calculator was another resource pointed to, in the survey, by 5% of the teachers. It was used by one of the observed teachers (Ca), where the orchestration was Detect-and-show, since he asked some children to present their solutions to multiplication tasks and contrast them with those of others (i.e., promoting activities of comparing, experimenting, and validating), although without discussing the reasoning involved. This DT use approached a transformative use of DT.

Finally, another resource was printed material downloaded from the Internet. We observed P doing this for the topic of addition and subtraction. For 24% of teachers this was a use of DT, but strictly speaking, DT is not used in the class.

In summary, the way that the participant teachers used DT was mainly as a replacement and amplifier, rather than as transformative; this has been noted by others (Santiago, et al., 2013; Trigueros et al., 2014). But we consider that DT resources that teachers used have limited possibilities for enhancing mathematics learning. The videos and the projected information were used, in general, to make the students listen, watch and transcribe explanations and information of some topic, without providing possibilities to experiment to do mathematics (a replacement type use). On the other hand, the interactive apps had an amplifying use, since they were used to practice skills (mental calculation), but they did not promote the exploration and understanding of concepts. Regarding the use of the calculator, since it only allows operations with quantities, its didactic use depends on the design of the activities that the teacher does (in Ca's case, it approached a more transformative use). In any case, it was necessary to promote teacher training and access to DT.

THE PROFESSIONAL DEVELOPMENT PROGRAMME

After the diagnostic phase, we designed and implemented a PD programme seeking to address some of the challenges identified in that study for DT integration. As a design-based research, the PD course was refined through two cycles; that is, we implemented two versions of the PD course with different cohorts over a two-year period. The 67 teachers who participated in the first study were invited to participate in that PD course and associated study; 15 of them accepted for the first cycle. Each PD course lasted 5 months (6 hours per week).

For the design of our PD programme, we took into account the schools' and teachers' context in this rural area of Mexico. We designed a course that would have official validity, in a venue close to the teachers' schools and/or homes. We chose a few offline (i.e., not requiring an Internet connection) digital resources, that could run on the old hardware available in the region's schools. These had to be easy for teachers to use, allowing for a significant and constructionist implementation in class, for "doing mathematics" rather than learning about mathematics (Papert, 1971).

The PD course consisted of three modules, each focused on studying a certain DT resource – respectively, diverse interactive apps for specific topics (including the Enciclomedia apps); dynamic geometry (GeoGebra); and Logo. The interactive applets in the first module deal with specific curricular contents and are easy to manipulate. GeoGebra helps address many geometry activities of primary-school. Finally, Logo also helps address the compulsory curricular contents of primary-school mathematics, through programming –allowing children to express themselves (construct), be creative, and develop computational thinking (an important skill in today's world). As explained in Sacristán & Enríquez (2020), we chose Logo over the nowadays popular Scratch, because it has less technical requirements, allows a more straightforward access to Turtle Geometry (allowing students to engage more directly in math-related tasks), and could be run offline on the available computers.

We didn't just introduce teachers to digital resources; rather, we aimed to promote a use that was transformative (Hughes, 2005), changing teachers' pedagogical practices and students' learning-processes and roles in the classroom. Thus, the work with teachers during the PD programme attempted to follow constructionism principles (Papert, 1991; Kynigos, 2015): e.g., by having tasks that would promote active, collaborative and autonomous exploration and expressivity of the learners. The tasks of each module were presented in four stages: (i) The study of the resource; (ii) the design of mathematics lesson plans integrating the digital resources studied in the course; (iii) the implementation of the designed classes; and, (iv) group reflections on the implementation experiences. Thus, teachers and trainers engaged in discussions of strategies for using the DT resources, taking into account the material limitations (e.g. of hardware), in terms of group organization, didactical interventions, etc.

For data collection, we used: (i) initial interviews of the teachers, and subsequent ones after each implementation of their lessons using DT; (ii) the lesson plans designed by the teachers during the course; (iii) in-class observations of the implementations of the designed lessons; (iv) the teachers' presentations of their class experiences, which they shared, during the PD course, with their colleagues. We then used the DAD approach (Gueudet & Trouche, 2012) to to study the changes in the participants' documentation systems (DS). Details of this are beyond the scope of this paper, but a comparison of one teacher's DS (see Table 2), before and after the PD course, is presented in Enríquez and Sacristán (2020).

Stage	Activity	Aim	Resources	Teacher's actions
		Initial DS *(without DT)*		
1	Solve problems in teams	Assess and review previous knowledge	Official activities and guidelines; Printed materials. Internet. The children's settings. Stories.	Following the resolution processes
2	Share solutions (whole group)	Deal with weaknesses and reinforce knowledge	Children's solutions Videos and concrete materials Exercises and problems	Guides Sets exercises Uses resources Decides problems for M3
3	Solve problems individually	Promote an expected learning	Official activities and guidelines; Printed materials. Internet. The children's settings. Stories.	Guides Deals with difficulties Sets problems
4	Solve textbook tasks	Assess the learning	Textbook	Guides. Assesses. Closes theme.
		DS1: *"Capacity measures [of liquid containers]"* ***interactive app***		
1	Pose questions on liquid volumes (liter, milliliter)	Assess and review previous knowledge	Questions	Pose questions & assess answers
2	Solve in teams problems on capacity of liquid containers	Promote an expected learning	Bottles, pails. Worksheet.	Guides
3	Solve individually problems on capacity of liquid containers	Promote an expected learning	*"Capacity measures"* ***App.*** Official activities. Worksheet.	Guides Deals with difficulties
4	Solve textbook tasks	Assess the learning	Textbook	Guides. Assesses. Closes theme.
		DS2: *Heights of triangles with* ***GeoGebra***		
1	Build triangles in teams (to describe characteristics)	Assess and review previous knowledge	Tangram Geometry set Colored pens and paper	Assess students' descriptions
2	Recognize the height of a triangle (individually)	Assess and review previous knowledge	Geometry set Pen and paper	Guides Reinforces knowledge
3	Solve individually the GeoGebra activity on heights of triangles	Promote an expected learning	**GeoGebra** Official activities. Worksheet	Guides Deals with difficulties
4	Solve textbook tasks	Assess the learning	Textbook	Guides. Assesses. Closes theme.
		DS3: *Constructing polygons with* ***Logo***		
1	Team game (characteristics of regular and irregular polygons)	Assess and review previous knowledge	Polygon bingo game Polygon comparison table	Designed and showed a comparison table of polygon characteristics
2	Draw regular polygons (individually)	Promote an expected learning	Geometry set Pen and paper	Guides
3	Construction of polygons with Logo (in pairs & individually)	Promote an expected learning	**Logo** Worksheet	Guides Deals with difficulties

Table 2. Changes in the documentation systems (DS) of one teacher (Enríquez & Sacristán, 2020)

As explained in Enríquez & Sacristán (2020), we observed that the integration of digital resources, as well as the training (the PD course), generated modifications to teachers' DS, with resources being substituted, or used in combination with previous ones. Each digital resource presented new possibilities (of implementation, knowledge and even motivation), as well as some limitations: The interactive app was easy to use and was adapted to the curricular content, although the learning tasks were restricted; GeoGebra was difficult to use, but allowed the teachers to design materials;

and Logo brought about more drastic changes, because it modified how the curricular content was approached, which was also difficult for teachers (see also Sacristán & Enríquez, 2020).

FINAL REMARKS

Our study showed, first, some of the difficulties in access and training that many teachers in rural areas of developing countries face. The design-based study of a DP course, then showed how the integration of digital resources into the DS of teachers is a complex but necessary task. In order to have meaningful DT integration, it requires the collaboration of teachers, trainers, researchers and authorities, as well as access to hardware, with a development of teachers' pedagogical technology knowledge (PTK) (Thomas & Palmer, 2014).

REFERENCES

Drijvers, P., Doorman, M., Boon, P., Reed, H., & Gravemeijer, K. (2010). The teacher and the tool: Instrumental orchestrations in the technology-rich mathematics classroom. Educational Studies in Mathematics, 75(2), 213-234. https://doi.org/10.1007/s10649-010-9254-5

Enríquez, H. & Sacristán, A.I. (2019). Cómo Profesores de Primaria Enseñan Matemáticas con Tecnología Digital: Dos Estudios de Caso de una Zona de Oaxaca. *5º Coloquio de Doctorado en Matemática Educativa*. Mexico City, Mexico: DME-Cinvestav.

Enríquez, H., & Sacristán, A. I. (2020). Integrating digital resources to the documentation system of a mathematics teacher in a Mexican rural primary-school. *Mathematics Education Across Cultures: Proceedings of the 42nd Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*, 2198–2207. https://doi.org/10.51272/pmena.42.2020-375

Gueudet, G., & Trouche, L. (2012). Teachers' Work with Resources: Documentational Geneses and Professional Geneses. En G. Gueudet, B. Pepin, & L. Trouche (Eds.), From Text to «Lived» Resources (pp. 23-41). Springer Netherlands. https://doi.org/10.1007/978-94-007-1966-8_2

Hughes, J. (2005). The Role of Teacher Knowledge and Learning Experiences in Forming Technology-Integrated Pedagogy. *Journal of Technology and Teacher Education*, 13 (2), 277-302. https://www.learntechlib.org/primary/p/26105/

INEGI/SCT/IFT (2021, Jun 22). *Comunicado 094. Encuesta nacional sobre disponibilidad y uso de tecnologías de la información en los hogares, 2020.* Instituto Nacional de Estadística y Geografía (INEGI) / Secretaría de Comunicaciones y Transportes (SCT) / Instituto Federal de Telecomunicaciones (IFT). México. https://www.gob.mx/cms/uploads/attachment/file/647466/ENDUTIH_2020_co.pdf

INEGI (2022). *Encuesta nacional sobre disponibilidad y uso de tecnologías de la información en los hogares, 2021.* Instituto Nacional de Estadística y Geografía. México. https://www.inegi.org.mx/programas/dutih/2021/

Kynigos, C. (2015). Constructionism: Theory of Learning or Theory of Design? In S. J. Cho (Ed.), *Selected Regular Lectures from the 12th International Congress on Mathematical Education* (pp. 417–438). Cham: Springer. https://doi.org/10.1007/978-3-319-17187-6_24

Papert, S. (1971). Teaching Children to be Mathematicians vs. Teaching About Mathematics. *Artificial Intelligence Memo* 249 / *Logo Memo* 4. http://dspace.mit.edu/handle/1721.1/5837

Papert, S. (1991). Situating constructionism. In Harel, I. & Papert, S. (Eds.), Constructionism: Research reports and essays (pp. 1-18). Westport, CT: Ablex Publishing Corp. http://www.papert.org/articles/SituatingConstructionism.html

Peres, W., Hilbert, M. R., & United Nations (Eds.). (2009). *La sociedad de la información en América Latina y el Caribe: Desarrollo de las tecnologías y tecnologías para el desarrollo* (1. ed). Santiago de Chile: Naciones Unidas, Comisión Económica para América Latina y el Caribe.

Sacristán, A. I., & Rojano, T. (2009). The Mexican National Programs on Teaching Mathematics and Science with Technology: The Legacy of a Decade of Experiences of Transformation of School Practices and Interactions. In A. Tatnall & A. Jones (Eds.), *Education and Technology for a Better World* (Vol. 302, pp. 207-215). https://doi.org/10.1007/978-3-642-03115-1_22

Sacristán, A.I. & Enriquez-Ramírez, H. (2020). An initial experience with Logo in a multigrade rural school in Mexico. In Tangney, B., Rowan Byrne, J. & Girvan, C. (Eds.), *Constructionism 2020* (pp. 147–157). The University of Dublin, TARA. http://www.tara.tcd.ie/handle/2262/92768 o http://hdl.handle.net/2262/92768

Sandoval, I. (2017). Matemáticas y tecnología digital: enseñanza y aprendizaje en la era digital. En Arredondo, M. (coord.) *¿Qué aprender? ¿cómo evaluar?* México: UPN.

Santiago, G., Caballero, R., Gómez, D. & Domínguez, A. (2013). El uso didáctico de las TIC en escuelas de educación básica en México. *Revista Latinoamericana de Estudios Educativos* 43(3). http://www.redalyc.org/html/270/27028898004/

SEP (2018) Programa del curso Aritmética. Números Natuales. Licenciatura en Educación Primaria. Plan de estudios 2018. Ciudad de México: SEP. https://www.cevie-dgespe.com/documentos/1104b.pdf

Sunkel, G., Trucco, D., & Espejo, A. (2014). *La integración de las tecnologías digitales en las escuelas de América Latina y el Caribe: una mirada multidimensional*. Cepal. http://repositorio.minedu.gob.pe/handle/123456789/3120

Thomas, M. O. J., & Palmer, J. M. (2014). Teaching with Digital Technology: Obstacles and Opportunities. En A. Clark-Wilson, O. Robutti, & N. Sinclair (Eds.), *The Mathematics Teacher in the Digital Era* (Vol. 2, pp. 71-89). Springer Netherlands. https://doi.org/10.1007/978-94-007-4638-1_4

Trigueros, M., Lozano, M.D. & Sandoval, I. (2014). Integrating Technology in the Primary-school Mathematics Classroom: The Role of the Teacher. In A. Clark-Wilson, O. Robutti, & N. Sinclair (Eds.), *The Mathematics Teacher in the Digital Era* (Vol. 2, pp. 111-138). https://doi.org/10.1007/978-94-007-4638-1_6

Trouche, L., Drijvers, P., Gueudet, G., & Sacristán, A. I. (2012). Technology-Driven Developments and Policy Implications for Mathematics Education. In M. A. (Ken) Clements, A. J. Bishop, C. Keitel, J. Kilpatrick, & F. K. S. Leung (Eds.), *Third International Handbook of Mathematics Education* (pp. 753–789). https://doi.org/10.1007/978-1-4614-4684-2_24