Researching Professional Trajectories Regarding the Integration of Digital Technologies: The Case of Vera, a Novice Mathematics Teacher

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Abstract This study examines the professional trajectory of a novice mathematics teacher, Vera, concerning her integration of digital technologies (DTs). This case study aims to: (1) characterise Vera's initial views and experiences as a student regarding the use of technologies for mathematics education and (2) analyse in depth how Vera integrates technologies while acting as a mathematics teacher. Vera was invited to participate in the study due to her positive attitude towards the use of digital technologies. Different moments in her trajectory as a preservice teacher and as novice teacher are analysed to highlight the different kinds of relationships she established with DTs. To analyse those kinds of relationships, we used a taxonomy of four metaphors that represent different types of relationships with technology: as *master*, *servant*, *partner*, and *extension of self*. The integration of new technologies into Vera's teaching practices is then analysed using five dimensions: *working environment, resource system, activity structure, curriculum script,* and *time economy.* Our results show a prevalence of Vera's relationship with technology as a partner or extension of herself, moving on to more sophisticated ways of integrating new technologies when she started teaching regularly at school. The study provides useful insights to support the rethinking of how technology use is introduced and taught within teacher education programmes.

Keywords Professional trajectories · Novice mathematics teachers · Integration of digital technologies · Teaching practices

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1 Introduction

Policies to incorporate DTs across the Latin American educational systems began in the 1990s following different models and with varied impact, depending on the country. Lugo and Delgado (2020) analyse the implementation of information and communication technology (ICT) policies in the regional education systems in the period since 2007, concluding that despite these policies, "it has not been possible to transform educational practices in such a way that they take advantage of DTs to improve teaching practices" (p. 22, our translation). This fact has a direct association with teacher education, particularly for initial teacher education where preparation in the pedagogical use of DTs is an ongoing demand. Thus, the authors recognise the need to "strengthen teacher education policies in the pedagogical use of digital technologies" (p. 22, our translation). This regional panorama related to teacher education includes the particular case of mathematics teacher education. Ruiz (2017) reports on the scarce training of mathematics teachers in the use of DTs in some Latin American countries. At the international level, Clark-Wilson, et al. assert that:

> …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 (2014, p. 1).

Six years after that publication, it seems that, at least in our country, Argentina, the problems associated with the integration of DTs in mathematics teacher education have still not yet been sufficiently addressed.

Alongside, the use of DTs has been recommended in the mathematics curriculum for secondary schools in Argentina (12–17-year-old students) since 2011, as well as in documents with didactic recommendations, since 2009, or the standards for mathematics teacher education since 2011. However, the use is still scarce in both contexts. Some reasons for this lack of use are related to institutional constraints, such as the lack of updated equipment or the existence of a conservative academic culture that does not promote the use of DTs at school. Other reasons are related to difficulties of access or insufficient digital literacy for both students and teachers. Furthermore, there are other reasons related to the limited use of DTs in schools such as poor trajectories in the use of DTs during the initial or in-service education of mathematics teachers and the low value attributed to DTs for mathematics education. At the same time, it is possible to find educational practices in mathematics classes in which DTs are significantly integrated into the didactical proposal of certain teachers (Mina, 2018; Sessa, 2018; Esteley, 2014). Therefore, we can find schools with absent or poorly integrated DTs, and schools with significantly integrated DTs.

Focusing on the last case, this chapter proposes an in-depth study of a novice female mathematics teacher's trajectory, called Vera, who has succeeded in integrating DTs in her mathematics classes.

Our study has two aims and a set of research questions that align with each aim.

Aim 1: To characterise Vera' initial views and experiences as a student regarding the use of technologies for mathematics education.

RQ1. What kind of experiences with DTs did Vera have while she was a student in high school or in the undergraduate teacher education programme at the university?

RQ2. What spontaneous views about the use of technologies for teaching and learning mathematics did Vera have?

RQ3. How did Vera use DTs while taking certain mathematics education courses?

Aim 2: To analyse in depth how Vera integrates technologies while acting as a mathematics teacher.

RQ4. In which ways did she integrate DTs in her first teaching practice, and later, as a novice teacher?

In the next section, we present a brief review of research related to our study.

2 Teacher Education and Digital Technologies

As highlighted in several studies, the integration of technology in mathematics classes responds to diverse and complex factors. These factors sometimes go beyond the mere disposition of the teacher, and some of them can become barriers to such integration. For instance, Desimone et al. (2013), and Ertmer and Ottenbreit-Leftwich (2010), identify different barriers such as: *resources*, *knowledge and skills*, *institution*, *assessment, subject culture* and teachers' *attitudes* and *beliefs*. Additionally, Drijvers (2015) identifies three factors which might inhibit or promote successful integration of DTs: the *teaching design*, the *role of the teacher*, and the *educational context*.

Ndlovu et al. (2020) report results from a study in which they investigated South African preservice teachers' (PSTs) beliefs about their intentions to integrate ICTs in their future mathematics classes. The study shows that attitudinal beliefs, and control over ICT use, shape PSTs' intentions to use technologies in classes. Based on their analysis, the authors recommend that technologies should be integrated into teacher education curricula, as early as possible, if we intend PSTs to integrate ICTs in their future teaching.

Gurevich et al. (2017) conducted a study involving a group of novice Israeli mathematics teachers who had attended a teacher education programme in which the use of technologies was encouraged. The authors conducted a longitudinal study to trace the participants' choices of technological tools and their attitudes toward the integration of technologies in mathematics teaching at three stages of their professional development: two stages as trainee teachers and a third as novice teachers. The paper reports a significant increase in the recognition of the technological benefits, and the incorporation of new technological tools for teaching when the participants became practicing teachers.

Drijvers et al. (2014) assert that the integration of DTs in secondary school mathematics classes has not yet been successful. Moreover, the authors consider that teachers are "crucial players" for such integration. Their study reports a gradual introduction of DTs in the classes of two experienced teachers in the Netherlands. They conclude that the process of integrating technology in mathematics classes is not simple and requires that teachers have an early immersion in the use of technology for teaching. In this sense, Ertmer and Ottenbreit-Leftwich (2010), and Hammond et al. (2009) point out that preservice teacher education that includes the use of technologies influences the type of teachers' future instruction and their capability to manage technological challenges.

Stein et al. (2019) study attitudes of novice mathematics teachers towards the use of technological tools in their teaching. They researched 14 novice teachers from Israel who studied in a technologically rich environment. In their results, they conclude that the novice teachers adopted digital tools for teaching and learning in a deliberate and rational way. Although the novice teachers recognised the benefits of using ICTs in their classes, they also pointed out some difficulties linked to institutional aspects.

Goos (2005) reports on PSTs' and novice teachers' pedagogical practices and beliefs about the integration of technologies into the teaching of mathematics in Australian secondary schools. The study focuses on cases of novice teachers who graduated from a technology-enriched teacher education programme. The author conducted her study from a sociocultural perspective in which teacher's beliefs can change in relation to the social environment, and the teachers' related goals and actions. The cases examined show that the development of the pedagogical identities of novice teachers related to the use of technology is shaped by constant negotiations between their teaching environments, actions, and beliefs. The study also evidences that novice teachers had to overcome some constraints of their working environments to integrate the technologies in their classes.

Considering the development of mathematics teachers' professional identities and agency, Losano et al. (2018) conducted an interpretative case study centred on one novice mathematics teacher who worked in a secondary school in the city of Córdoba (Argentina). As a student teacher, she had experienced the possibility of working in technologically rich environments. In her first years as a teacher, despite certain constraints in her working environment, she found ways to integrate technologies into her mathematics classes. She mainly developed her professional identity and agency in relation to technologies by incorporating the feasible teaching practices of her school, the positions she could occupy as a newcomer in the institution, and also the cultural practices and discourses embodied during her preservice education.

This literature review reports a small sample of studies that, in placing the focus on teachers and their educational trajectories, identify factors that hinder or favour the process of technological integration in mathematics classes. Teachers are recognised as central actors in this integration. Hence, we consider that our study complements existing research findings by providing evidence of how a novice teacher's initial educational process impacts the ways in which she integrates DTs in her later classes.

3 Theoretical Framework

In this section, we describe some framing ideas regarding teacher education related to DTs, and outline the dimensions that are considered to support the analysis of Vera's integration of technologies.

Teacher education and the relationships that teachers establish with DTs can be recognised as influential factors for the integration of DTs in mathematics classes. These relationships are forged by their experiences within different environments. More specifically, (preservice or in-service) teachers' trajectories and previous personal experiences constitute the matrix from which teachers interpret, and make sense of themes, debates and tasks that are pertinent in their respective learning environments (Menghini, 2015; Edelstein, 2011; Vezub, 2009).

For Vezub (2013), teachers' professional trajectories[1] result from the interaction of multiple objective elements (e.g., the context of teachers' performance, initial and continuous education) and subjective ones (e.g., their motivations and expectations). The author proposes the idea of trajectory to emphasise teacher education as a complex and long-term process that articulates initial and in-service education. Vezub considers that professional trajectories are neither linear nor uniform, and that they can be seen as the result of actions and practices developed by individuals in specific situations over time. The interactions between the existing structures of opportunities, and the appropriations that individuals achieve, according to their own objective and subjective possibilities, are synthesised through these trajectories.

Vezub's ideas help us to understand that the integration (or not) of DTs in teachers' professional trajectories is conditioned by the existing opportunities and the possibility they have to take advantage of such opportunities. According to Borba and Villarreal (2005), technologies may reorganise teaching and learning practices, curriculum content, and ways of thinking and knowing. Particularly, in mathematics

[1] Vezub (2013) proposes the term *trajectory* considering Bourdie's use and definition of the term when referring to the trajectories of subjects in a given social field.

classes, DTs are understood as actors that demand new pedagogical approaches. However, such pedagogical approaches that seek to integrate DTs[2] in the mathematics classes may not be implemented, due to the multiple factors listed above, if the actors involved in the classroom do not form significant relationships with the technologies.

Goos et al. (2000) developed four metaphors to form a "taxonomy of sophistication with which teachers and students work with technology" (p. 307). This taxonomy describes four different roles for technology in relation to teaching and learning interactions:

- *Technology as master*: the user is subordinate to the technology and is only able to make use of some features due to the limited individual knowledge and the force of circumstance.
- *Technology as servant*: the user knows the technology but uses it in a limited way to support their usual way of performing tasks.
- *Technology as partner*: the user makes creative use of technology to increase the power over their learning.
- *Technology as extension of self*: the user incorporates technological expertise as an integral part of their repertoire as teacher or student. In this case, powerful use of technologies "forms an extension of the user's mathematical prowess" (p. 312), and also of the pedagogical skills of teacher users. This is a type of relationship with technology that involves the highest level of functioning.

The metaphors of Goos et al. (2000) constitute an analytical tool that allows us to analyse the type of relationship with technology that Vera built throughout her educational trajectory. Alongside, the interplay between the *five structuring features of classroom practice* for understanding the integration of new technologies into daily mathematics classroom practice proposed by Ruthven (2009) offers a rich analytical lens to scrutinise Vera's teaching practices both as a preservice teacher and as a novice teacher. Working from a perspective that focuses on the daily work of teachers, Ruthven identifies five key structural characteristics of classroom practice that relate to technology use: *working environment, resource system, activity structure, curriculum script,* and *time economy.*

The *working environment* concerns the physical arrangements and class organisation required for the introduction of technologies for teaching. Technologies have not only the potential to expand the range of tools and materials available to support school mathematics, but they also imply the need to build a consistent *resource system*. The use of DTs may require a set of adaptations of certain established repertoires in the construction of classroom activities that frame the actions and interactions between teachers and students or among students, which would imply the creation of prototypical *activity structures* or cycles for some types of lessons.

[2] Briefly, for the purposes of this article, we are specifically interested in DTs, which include the internet, any type of software (GeoGebra, spreadsheets) and programming languages (such as Python).

The incorporation and integration of instruments and resources require that teachers make new choices, organisation, and sequencing of the content to be taught, alongside the activities and resources for teaching. This implies that teachers will need to reorganise their *curricular scripts,* into which the activities and tasks are contemplated. These scripts are influenced by the resources that are incorporated, the possible students' difficulties and the learning environment.

Finally, the introduction of DTs can influence the *economy of time* in the class, changing the "rhythms" of work and the creation of "didactic time". This didactic time is measured in terms of the advancement of knowledge within the classroom.

4 The Contextual Frame of the Study

Our research was conducted with the participation of Vera, a novice mathematics teacher, who graduated from the mathematics teacher education programme at the University of Córdoba (UNC) at the end of 2017. For this study, it is necessary to consider two main contexts that frame our results and analysis: the UNC teacher education programme, and the school where Vera has been working as a mathematics teacher since 2018.

4.1 Vera's Educational Context as a Preservice Teacher

The teacher education programme at UNC that prepares mathematics teachers for secondary schools lasts 4 years. Sixty six percent of the curriculum courses are devoted to mathematics and are mainly taught by mathematicians. The remaining courses deal with educational issues and are taught by pedagogues or mathematics educators. Within this second group of courses, there are two annual courses which are central for the PSTs' education: Mathematics Education (ME) and Teaching Methodology and Practice (TMP). They are included in the third and fourth year of the programme, respectively. Both are 30 weeks courses of two 4-h classes per week. Every year since 2011, at least one of the authors of this chapter has taught on these courses.

Within the mathematics courses of the teacher education programme, PSTs experience few mathematical activities in which DTs are significantly integrated. Consequently, work with technologies during the ME and TMP courses is essential if future teachers are to be expected to integrate technologies into their school mathematics classes.

In the ME course, several themes are studied, among them, the use of technologies. For this course, we adopt the epistemological perspective presented by Borba and Villarreal (2005), which assumes that knowledge is produced by collectives of humans-with-media[3] and that cognition is a social enterprise that includes the media with which knowledge is produced. During the course, both the teachers and the PSTs discussed these ideas, analysed examples, and recognised the role of the media in the processes of knowledge production as well as in the mathematical teaching and learning processes. Moreover, they discussed possibilities, scope, and conditions for using technologies in educational contexts, and they analysed synergistic pedagogical approaches for the use of DTs. Mathematical tasks are solved using different technologies, such as calculators, GeoGebra, or PhET Interactive Simulations.[4] The advantages and disadvantages of the use of technology in different contexts arise from the texts studied, personal experiences, discussions, and the tasks solved during the course.

Although the topic "DTs in mathematics education" is specifically addressed over a period of one and a half months, DTs are also present in the treatment of different curriculum topics throughout the ME course. For example, when mathematical modelling is studied as another important theme, the synergy between technologies and the modelling process arises naturally when the PSTs develop free open modelling projects (Villarreal et al., 2018).

The path proposed in the ME course provides some foundational tools and strategies for the TMP course, which many PSTs attend the following year. The TMP course's central aim is for student teachers to develop their first teaching practice in secondary school classes (which lasts for 1 month). During the first four-month period of the TMP course, issues corresponding to the macro-educational and the micro-didactical levels of the curriculum are addressed. The analysis of certain learning environments (previously introduced during the ME course) are deepened and the main variables that influence lesson planning are discussed.

The PSTs first teaching practice at secondary schools is carried out in groups of two or three within the same school and grade, under the supervision of one of the TMP course teachers and the secondary school teacher of the grade assigned for the teaching practice. Before teaching starts, each group conducts observations in the assigned classes, develops lesson plans, prepares materials and elaborates scripts for each class, anticipating possible students' actions or difficulties, interventions and concerns. The overarching work of teaching is continuously under revision according to the emerging conditions and requirements of the school. If schools are richly equipped with DTs, PSTs must integrate them into their teaching. When conducting the teaching practices, one PST oversees the class, another PST observes it, acting as an assistant, if necessary. When the teaching practices conclude, each group of PSTs writes a report and prepares an oral presentation to share their work with teachers and classmates on the PST programme.

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[3] For these authors, media means any kind of tool, device, equipment, instrument, artefact, or material resulting from technological developments, but also includes orality and writing.

[4] PhET Interactive Simulations (https://phet.colorado.edu/) is a non-profit open educational resource project at the University of Colorado Boulder (USA), which provides a suite of research-based interactive computer simulations for teaching and learning physics, chemistry, biology, earth science, and mathematics.

4.2 The Context of Vera's Current School

At the beginning of the 2018 school year, Vera worked temporarily in two schools in the city of Córdoba for a short period of time. They were part-time jobs. Then, she quit those jobs to concentrate her teaching at the secondary school where she is currently working, because this institution offered better working conditions. At this privately managed public school,[5] Vera teaches mathematics to 2nd- and 3rd-year students (13–15 years old). During the last 10 years, this institution has been encouraging the use of DTs for the teaching and learning of all subjects and for all courses. Each classroom has wifi internet access and is equipped with a digital board connected to a data projector and a chalkboard. Each student has a tablet or a personal mobile phone with specific software for mathematics, such as GeoGebra, and classic office suite.

Knowing this context supports us to understand and make sense of Vera's answers, ideas, and different decisions within the context of her trajectory as a teacher with respect to DTs.

5 Methodological Procedures

We conducted qualitative research within the interpretative paradigm (Denzin & Lincoln, 2018) as an in-depth study of Vera's case. She was selected to participate in the study for several reasons. We had both taught Vera during the teacher education programme at UNC and so had observed her trajectory as a student and were aware of her positive disposition towards the use of DTs for learning or teaching mathematics. Two years after finishing her studies at the university, we learned that she had started working in a school that has both the all-important technological infrastructure and a favourable position towards the pedagogical use of DTs. Consequently, Vera had now begun to integrate DTs into her classes extensively and we were keen to research the trajectory of her development in this respect.

The study comprises two parts which align to the aims for the study, which focus on Vera's educational and professional trajectories. The former (addressing RQs 1, 2 and 3), refers to Vera's experiences with DTs as a high school student and her first 3 years as a PST. The latter (addressing RQ 4), is based on the analysis of data collected during Vera's first teaching practice as a PST at UNC and an interview conducted in her role as an in-service teacher.

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[5] In Argentina, privately managed public schools are those in which the school building and its entire infrastructure belong to a private entity. However, the school employees' salaries are paid by the State. In these schools, students pay a monthly fee that is not as high as the fees of a fully private school.

The taxonomy proposed by Goos et al. (2000), and Ruthven's (2009) conceptual framework are used as analytical tools.

5.1 Vera as a Student

We draw on data from the ME course that Vera attended in 2016, which comprised: individual written answers to tasks related to DTs, the written report of the modelling project carried out by Vera's group, the files produced with software (GeoGebra, spreadsheets, Python, etc.) when solving the problems of the modelling project or other mathematical problems, the slides for the oral presentation of their modelling project, videotape recordings of such oral presentation, and our field notes.

To address RQs 1 and 2, we analyse Vera's written response to a task posed by the teacher to the whole class, when the "DTs in mathematics education" topic was studied in the ME course. In this task, the PSTs were asked to explain (a) their prior experiences with the use of technologies in mathematics classes, and (b) their views about the relationships between the use of technologies and the teaching and learning of mathematics. From this analysis, we aimed to characterise Vera's initial views and experiences regarding the use of technologies for mathematics education.

To address RQ 3, we focus on the analysis of Vera's productions resulting from an intensive use of DTs during a modelling project.

5.2 Vera Acting as a Mathematics Teacher

The data associated with the second aim of the study originate from the written report[6] (Lovaiza & Marchesini, 2017) on Vera's first teaching practice and a semi-structured interview protocol. The interview, which was conducted virtually in 2020 by the second author, probes Vera's reflections and views on her integration of DTs into the ME course, her first teaching practice and her current practice as a novice teacher. The initial questions were:

1. Do you remember in which of the UNC courses you used DTs and for what purpose?
2. The year after you graduated from UNC, you taught at two schools. In those schools, did you use DTs?

[6] This report is open access and published under Creative Commons license.

3. Regarding the school where you are currently working:
   (a) What do you think of the infrastructure offered by the school for the use of DTs?
   (b) Do you incorporate the DTs into your daily class routines?
   (c) How do you organise and complement the resources you use?
   (d) How do you select and organise the activities?
   (e) How do you think that the use of DTs influences the interactions in the classroom or the didactic time?

Before concluding this section, we include a statement of compliance with ethical standards. Four PSTs including Vera gave us their consent, via email, to use in this study the information from their modelling project written report. Moreover, they were also informed by email about this chapter and authorised us to publish their report's images and content. Vera was informed about the aims and scope of the study and the use of her responses during the interview, both at the time of the invitation to the interview and prior to its start. Both Vera and the other three PSTs were given the opportunity to request clarification on what would be reported. Anonymity was also guaranteed.

6 Results

In this section, we present the results with respect to how Vera was developing her relationship with the DTs. We consider instances of her approach to technologies as a high school student and as an undergraduate student. Then, we report ideas and experiences of the integration that Vera developed as a novice teacher. Figure 1 presents a timeline showing Vera's trajectory.

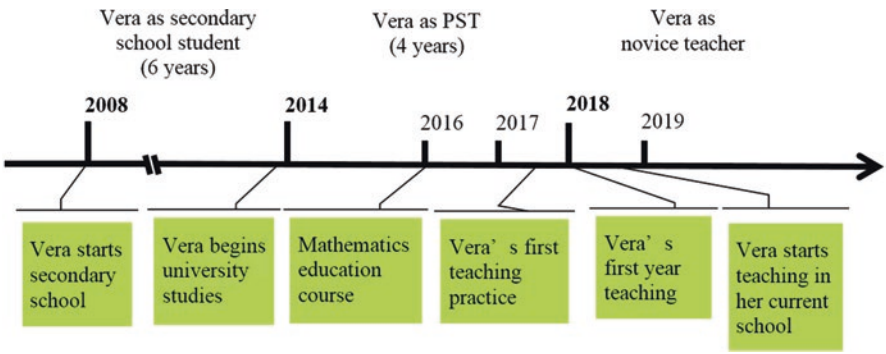

Fig. 1 A timeline of Vera's trajectory

6.1 Vera's Relationship with DTs in Different Educational Contexts

Vera had no experience of using DTs at her high school. She admitted, "…I have not used much technology in mathematics classes. In other subjects, yes, we had to prepare PowerPoint […] as the main task". Besides, she stated that in her mathematics classes, scientific calculators were allowed only to solve computations involving trigonometrical, logarithm or exponential functions. However, when students had to analyse and plot functions, the calculator was not allowed as the task had to be handwritten. According to Goos et al.'s (2000) taxonomy, the role of technology promoted in Vera's high school can be associated with the metaphor of *technology as servant* since it is not used in a creative way, but only for making routine computations.

Vera was asked about the use of calculators when she was a preservice teacher, on which she reflected:

> …the fact that they [the students] are allowed to use the calculator in certain topics to be taught or studied does not make the student think or reason less. I simply see it as a tool that was made to be used as the ruler and the compass.

These words show Vera's special disposition towards the use of DTs, revealing her open-minded position in relation to the use of the calculator which differed from her college classmates' predominant position.

When Vera took the mathematics courses during the teacher education programme, the use of DTs was limited. For instance, not all mathematics faculty embraced the use of DTs, the mathematical tradition was still handwritten mathematics, and the examinations did not allow DTs (including calculators) to be used. More specifically, GeoGebra software was used to make geometrical constructions in a course on Euclidean geometry, but not to experiment or make conjectures. Alongside the mathematics courses, basic notions of programming using Python were introduced in a course on computer programming and applications of numerical methods taught by physicists. At the same time, during the ME course, Vera used DTs profusely. For example, during the aforementioned collaborative mathematical modelling project, and for communicating the progress of such work throughout her different classes.

For the modelling project, Vera and a group of other three students decided to study the following theme: "Looking for letters in magazines for school homework". A common homework for children in the first grades of primary schools in Argentina is to find and cut out, from different magazines, letters or words that contain a combination of certain letters. This theme was chosen since one of the members of the group remembered that she always found it difficult to complete this activity because she had very few magazines at home. The group established some assumptions to solve some typical school tasks related to this theme and posed some questions such as:

- what is the minimum number of magazines needed to find all the letters of our alphabet?

- or, given a specific task such as to cut out 3–5 words that are written with MB or with, BR or with CH, what is the probability of finding that number of words on one page of a magazine?,
- or what is the probability of finding that number of words on more than one page of a magazine?, and what about using more than one magazine?

The group established a set of assumptions, which included: a standard magazine has about 45 pages, a child can look for words or letters in 4 magazines at most, and a child can cut letters of at least 1 cm high. The group also defined the following probabilistic condition: an event is, in their words, "sufficiently probable" when its probability is greater than or equal to 0.7. The selected tasks and the assumptions were established following consultation with elementary school teachers.

To respond to their questions regarding the probability of accomplishing a given specific school task, Vera and her group turned to Python programming. For this, having used a word processor to reproduce the sentences (with letters of at least 1 cm high) from a sample of 30 magazines of 45 pages each, they programed a code to count words according to the selected task. Once the database was built, they used a spreadsheet to calculate probabilities, make charts and graphs. In some combined tasks, they also wrote programs within the spreadsheet itself. Figures 2 and 3 illustrate the work developed within Python and the spreadsheet, respectively.

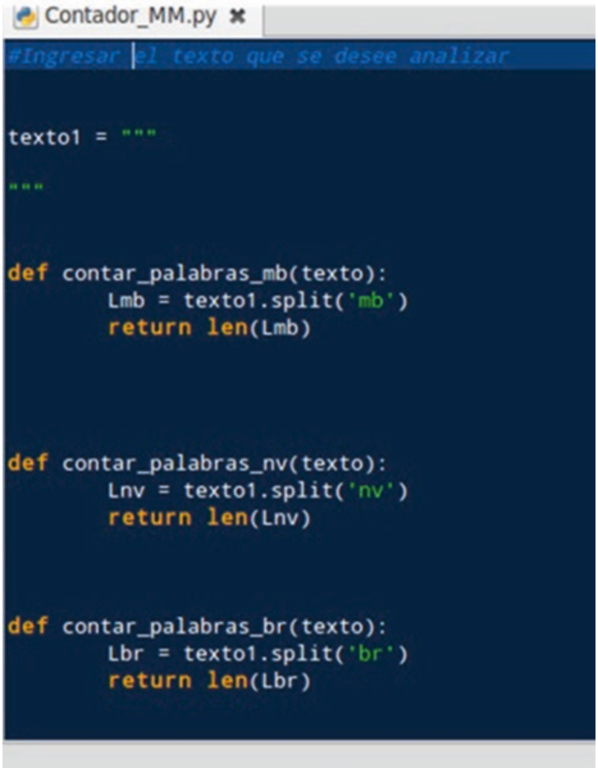

Fig. 2 Python Code. (Source: students' written report)

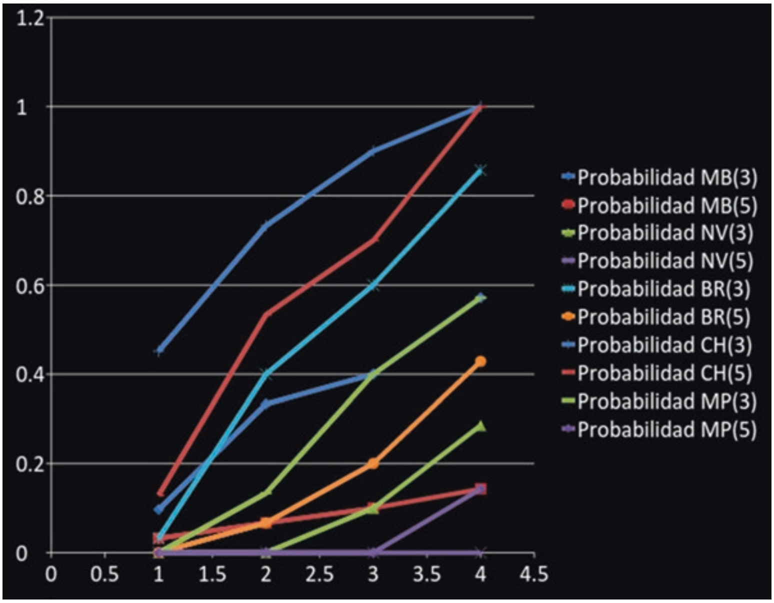

Fig. 3 Graph of probabilities of achieving the tasks (finding 3 or 5 words) versus number of magazines used. (Source: students' written report)

Among their conclusions, the group indicated that, to be able to find all 27 letters of the alphabet with "sufficient probability", it was necessary to have at least 3 magazines to cut. It would not have been "sufficiently probable" to perform any of the proposed tasks with only one magazine. Moreover, they were not aware of the difficulties that these types of activities could bring to the children and their parents, especially at the current time when fewer and fewer magazines are available at home.

In the final report of the modelling project, Vera and her colleagues recognised the importance and support of the various technologies (Python, office suite, and Google docs) used for various purposes at different phases of the modelling project. They wrote: "They [the DTs] allowed us to streamline the organisation and analysis of data and calculations as well as to visualise the results obtained in a clearer and more concise graphic way". In this case, DTs were *partners* that contributed to the efficiency of the group's work, facilitating and enhancing the mathematical production. In addition, the students stressed that they had learned how to use the technologies they needed for their modelling project, more specifically programming in Python and spreadsheet, in a collaborative way. The project was carried out by a thinking collective of *humans-with-DTs*, showing that the technologies were integrated not only as an *extension of* each isolated individual, but as an *extension of themselves*.

In the following subsections, we will focus on Vera's use of DTs to teach mathematics in the school setting as a PST and as in-service teacher.

6.2 Vera's First Teaching Practice: DTs as Media to Teach and Facilitate Mathematical Production

During 2017, Vera and her pedagogical partner carried out their first teaching practice in a public high school. They worked with students of 12–13 years of age. The mathematics theme for their practice was angles and triangles, which included the study of pairs of special angles formed when parallel lines are intersected by a transversal line, the classification of triangles, and congruence in triangles: definition and properties.

For the lesson plan, as detailed in the written report of their practice (Lovaiza & Marchesini, 2017), they considered a general objective: "…to generate a teaching proposal that covers the required knowledge…, taking into account the importance assigned by the institution to the development of critical and argumentative thinking of students" (p. 31). Therefore, they claimed: "[we] decided that our plan should be permeated by the use of technologies" (p. 32). The resources and didactical materials used in the classroom were: textbooks, PSTs' notes, blackboard and chalk, a data projector, PowerPoint software, computers, students' mobile phones, GeoGebra software, rulers, pairs of compasses, protractors, and photocopied texts with activities and definitions.

Guided by their general objective and decision to use DTs, they organised the lesson script by considering three didactic units: definition, argumentation, and the congruence of triangles.

For the first didactic unit, the notion of mathematical definition was considered as a teaching object. For this purpose, they worked on what a definition is, the parts of which it is composed, and examples and counterexamples generated for a particular concept. They also designed a teaching plan in which the knowledge about definitions was then applied to define, and then classify angles.

The second didactic unit focused on the justification of mathematical statements. They designed definition analysis activities to support arguments about the validity of any given statement. In this case, they appealed to concepts and relationships between angles defined by two parallel lines and a transversal one. They also proposed activities for students to elaborate written and oral arguments, validating their own and other classmates' statements, by using geometric figures, hand drawn on the chalkboard, or cut from paper, or constructed in GeoGebra and GeoGebra hand-animated dynamic figures as didactical resources.

In the third didactic unit, they applied the concept of congruence already developed within the first unit, which addressed mathematical definitions. They designed congruent triangle construction activities "using GeoGebra as a teaching resource to elaborate conjectures about the properties of and criteria for the congruence of triangles" (p. 33).

Some of the GeoGebra files designed by Vera and her partner are shown in Figs. 4 and 5. Figure 4 shows an image of the animation in GeoGebra used to study the congruence of the corresponding angles between two parallel lines cut with an intersecting transversal line. Figure 5 shows part of the process demonstrating the

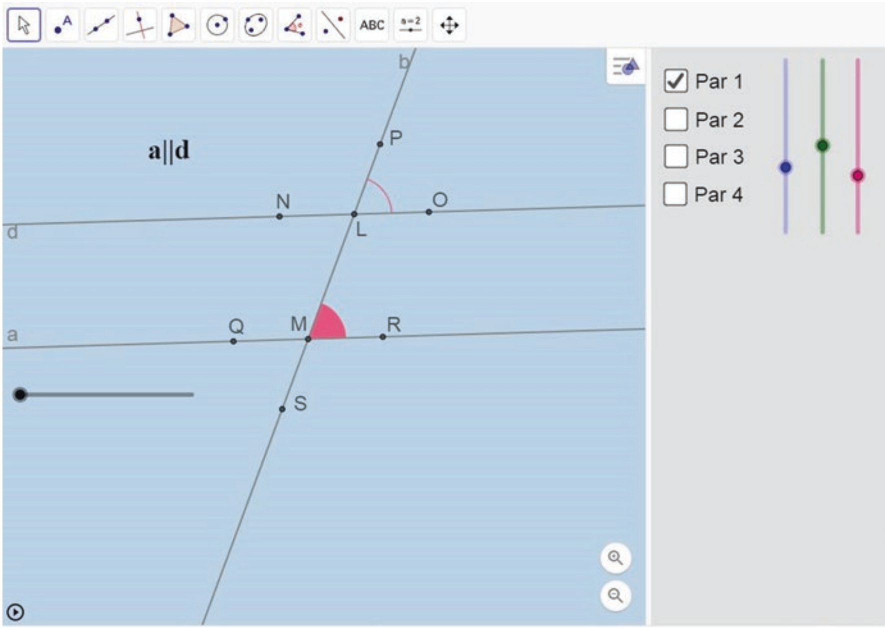

Fig. 4 Image of an animation in GeoGebra. (Source: Lovaiza & Marchesini, 2017, p. 48. Accessible at https://www.geogebra.org/m/esPBcwR3)

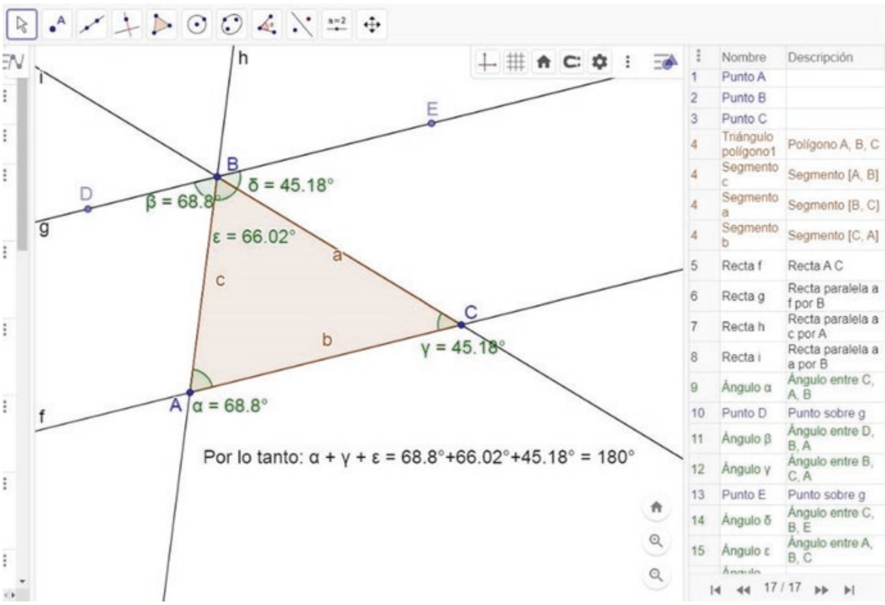

Fig. 5 Sum of the interior angles of a triangle and the construction protocol, on the right. (Source: Lovaiza & Marchesini, 2017, p. 55. Accessible at https://www.geogebra.org/m/naaEb7xY)

property of the sum of the interior angles of a triangle referring to the argument of the congruence of angles determined by two parallel lines cut with an intersecting transversal.

During her first teaching practice, Vera and her partner made an intensive use of DTs. This use was not only for the purpose of exposing or discussing ideas or arguing with their students, but they also proposed tasks mediated by DTs for them. Such tasks invited the use of DTs in small groups or collectively in order to explore situations, propose conjectures and move forward with arguments to support the conjectures. Among the multiple reflections made by Vera and her pedagogical partner in their final report, they highlighted:

> The use of technologies was fundamental for our practices as they permeated and conditioned all the didactic units. Software such as PowerPoint and GeoGebra allowed students to construct figures, analyse them, generate conjectures and make assumptions, question them, and validate them. They facilitated the creation of experimentation and debate scenarios that favoured group interactions and the cooperative generation of knowledge as collective knowledge… (Lovaiza & Marchesini, 2017, p. 108).

As highlighted above, during Vera's first teaching practice, technologies were essential, not only for her, but also for her students. As reported by the pair, the initial didactic decisions that related to the selection, organisation and sequencing of the activities and corresponding resources played a fundamental role in influencing the quality and type of knowledge produced by the students. For Vera, technology had become an *extension of herself* as a teacher, thus encouraging students to *think collectively* among themselves and with the DTs.

It is worth noting that, whilst Vera was answering the first interview question, she explained that both her group's mathematical modelling project and her first teaching practice were instances that contributed and motivated her to use various technological resources as a teacher.

6.3 The Integration of DTs into Current Vera's Daily Work

Vera began teaching in two high schools in Córdoba for a short period. When asked if she had used DTs in those schools, her answer was short and clear: "[…] no, because the resources [DTs] were not available. That's why". And she quickly pointed out that in contrast, at the school where she is currently working, she frequently uses DTs, asserting that "[…] in this school, I use Excel, GeoGebra… a lot, for the students to explore and conjecture, mostly […] I also use the digital screen, the Activ[7] […]".

In Vera's current school, the work with DTs did not require students and teachers to move to a special place away from their usual mathematics classroom. The classroom had wifi internet access, the students had tablets or mobile phones for personal

[7] She refers to ActivInspire, a lesson delivery software for interactive displays. The digital Screen and the Activ are installed in the classroom.

use and the teacher had a desktop computer connected to a digital screen. Since the available infrastructure facilitated the introduction of the DTs and it did not involve changes in the working environment or in the physical layout, it was not necessary to modify the rhythm of the work routine in the classroom.

For Vera, this new *work environment* was conducive for using DTs, enabling her to retrieve familiar knowledge and skills. But this new environment also meant that she had to broaden her knowledge. As Vera explained, while she was teaching, she was learning to use new resources such as the digital screen. She began to learn by observing her colleague's work, and then attended a course offered at the school in which she learned to use the digital screen and the school's Moodle platform.

Although this *work environment* allowed her to access all the DTs needed for the daily work in the classroom, she did encounter some technical problems such as "the electricity gets disconnected, the internet doesn't work, or the screen doesn't turn on…" For Vera, what was important for *the daily routine of the mathematics classes* was not only the access to DTs, but the activities proposed that included the use of DTs. She explained:

> […] I find it hard to imagine my classes without technology as a medium. Obviously, not always the same type of use, nor with the same intensity or the same role. That is, there are classes where it is auxiliary. For example, the use of a calculator or designing a small presentation to share. And I make other [uses] in which the class is based on observing a GeoGebra animation and making conjectures, or making a construction which we could not do without the tool [the DTs] […] that depends on the goals established for the class.

In the *scripts* for her daily classes, Vera incorporated activities, purposes, DTs and other resources. However, the *curriculum* is shaped through the students' interactions with DTs. For instance, Vera indicated that she usually tried to follow a structure for each class. She begins by presenting the objectives and the organisation of the class. In the classes, the teacher and students interact using presentation slides (previously prepared by Vera) to introduce a new topic or to assign tasks for her students that are displayed using the digital screen. For group activities during the class, each group prepares presentation slides and some groups are chosen to presentation their work to their classmates using both the digital display board and the chalkboard. When taking notes or completing activities, students can use either pen and paper or a digital pen and tablets, or a combination of both.

Although Vera and her students have a wide range of available materials or tools, she preferred to develop her lesson material using the digital screen since the resulting work can always be saved as a pdf file. Following the lesson, she uploads the files to the Moodle virtual classroom so that everyone could have access to these materials. In some instances, she also promotes the use of compasses, rulers, or other geometric tools, or pencil and paper to encourage the development of fine motor skills. This integration of non-digital media such as these is also motivated by the institutional factor that tests must be handwritten to conform to the school rules.

By recognising the school's specific demands, Vera was able to overcome the challenge of building a *coherent resource system* composed of digitals and non-digital tools.

When dealing with DTs in the classroom, Vera highlighted: "I think that the DTs encourage interactions in the classroom, well now [she referred to the classes during the COVID-19 pandemic], in this virtual model, the Moodle platform favours discussions, […] the production of conjectures and explorations".

When referring to the production of conjectures, she explained, "that was the theme of my first teaching practice, and I continue to implement it", referring to her current pedagogic approach. When asked about the relationships between DTs and time, Vera noted that the time spent working with DTs is based on its contributions to students' learning and not to the *economy of time*. She illustrated this idea with an example: when teachers have to explain the property of the sum of the interior angles of a triangle, they may resort to a time-saving strategy of informing that the sum is 180°. But, if they want the students to discover such property, they can propose exploratory activities using DTs. In this last case, the nature of the knowledge and learning will be more meaningful, and the time invested will become a *didactic time*.

Didactic time for Vera seems to be measured in terms of the richness of the interactions between the participants in the classroom as well as their progress in learning mathematical concepts and processes. The economy of time and rhythm goes beyond the time measured by the clock, but it seems to be measured in terms of the advances in the students' learning.

Vera's interview responses evidence a *work environment* that is conducive to the integration of DTs, which seems to start when she produces the *curriculum script* for her classes. The *script assembles goals, a structure of activities*, a *coherent system of resources*, and a *didactic time* that privileges the students and their learning as well as the production of rich mathematical and technological knowledge. In that sense, most of Vera's answers put into play an interesting network of ideas in which the dimensions proposed by Ruthven (2009) are evident.

Finally, Vera summarises her vision of the deep sense she perceives about the integration of the DTs in her words, "[…] technology is omnipresent at this time. Kids always have their mobile phones in their hands, so they always have their maths folder[8] in hand".

7 Discussion and Conclusions

Our study contributes to the body of research on the professional trajectories of mathematics teachers by considering one teacher's passage from a PST to becoming a teacher into the first years of teaching and focuses on issues related to the integration of DTs in this context.

[8] It has been translated as *math folder* to refer to what in Argentina we know as *carpeta de matemática*, which is a school material in which a student can store their mathematics work, written assignments, class notes, etc. In the case of a mobile phone, the *carpeta de matemática* would be a folder containing files with all the work done in mathematics class.

As reported in the literature, current integration of DTs in mathematics classes, in which teachers are recognised as crucial players, is not satisfying the initial expectations with respect to improving mathematical learning (Drijvers et al., 2014). Many authors (Desimone et al., 2013; Ertmer & Ottenbreit-Leftwich, 2010; Drijvers, 2015) have listed factors that can act as barriers or promoters of such integration. In the analysis of Vera's case, it is possible to observe some of these promotional factors in action. For example, the presence of an *educational context* that favours the integration of DTs in the school environment resulting from an infrastructure that guarantees access conditions or Vera's positive *attitude* towards the use of DTs. This attitude was evidenced in: her position towards the use of calculators; the profuse and creative use of DTs during the development of a group modelling project; the type of tasks she proposed in her first teaching practice; and her statements about the evolving role of DTs in her current professional life. Our study provides evidence that supports the points made by Ertmer and Ottenbreit-Leftwich (2010) and Hammond et al. (2009) regarding how experiences with DTs during teachers' initial education influence and impact upon their emerging teaching style.

In Vera's case, the use of DTs in the mathematics teacher programme at the UNC was particularly intensive within the ME course and during her first teaching practice. In the ME course, PSTs carried out a mathematical modelling project in groups. The project conducted by Vera and her colleagues using multiple technologies, discussed in this chapter, was part of the data used in a previous study we reported on Villarreal et al. (2018). In that article, we showed evidence of the synergy between the use of technologies and the development of modelling tasks. The analysis we present in this chapter constitutes new evidence of such a synergic relationship and brings an example of a type of task that allows a natural integration of DTs in mathematics classes. Borba and Villarreal (2005) point out that the association of exploratory activities, technology and modelling exhibits a natural synergy. Another example of tasks that call for the integration of DTs in a significant way is the creation of learning scenarios where technologies allow exploration, production of conjectures and arguments to justify their validity, as Vera and her pedagogical pair did during their first teaching practice.

Throughout Vera's trajectory, we could observe the different types of relationships she established with technologies. Following the taxonomy of Goos et al. (2000), we found instances in which technology was assumed as a *servant*, but it also assumed other significant roles. For example, when a collaborative modelling project was being developed, a collective of humans-with-DTs was constituted, and technology was assumed as a *partner*, and even became an *extension of selves*. As observed by Goos (2005), the ways of working with DTs can become more varied and sophisticated over time, moving from using technology *as a servant* to *an extension of self*.

Despite the limitations of the type of research carried out (an individual case study) in terms of the possibilities of wider generalisations, details of a novice teacher's professional trajectory in relation to DTs provide clues for rethinking the actions in our teacher education programme in which DTs are completely absent from the teaching of several mathematics courses. In other courses, DTs have a mere auxiliary role, acting as *servants*, which means that they are neither integrated meaningfully into the teaching or learning processes nor does their presence result in changes in the task, DTs merely accompany the usual performance of tasks. It is therefore necessary to change the approach from using technology *as a servant* to using technology as a *partner* and as *an extension of self* (Goos et al., 2000). However, as pointed out by Goos, this is not an easy task. For this to happen, during initial teacher education, it is necessary to create learning scenarios involving tasks that demand technology use that go beyond the teacher-centred lecturing pedagogy that is typical of the Argentinian university context. As previously highlighted, modelling or explorations-with-technologies scenarios are a possible option to generate another type of relationship with the DTs.

Vera's case was chosen due to its uniqueness. The relationship that Vera has established with DTs can be characterised as an *extension of self*. In her classes, this underpins her significant integration of a variety of DTs, both in terms of the types of tasks posed and in the ways that students participate. Vera's earlier experiences as a student alongside the current *work environment* in which she is immersed, facilitate the organisation and management of her students' access to DTs. The *system of resources* developed by Vera, enables coordinated work between digital and non-digital technologies. Such coordination is related to the choice of a *system of activities* declared in her *curricular script*. The time spent in the classroom is for Vera a true *didactic time* measured in terms of students' learning and knowledge.

Most recently, Vera's knowledge, the available school infrastructure, and her own disposition towards the integration of DTs, facilitated a quick adaptation of her practice to the new requirements of a wholly virtual teaching environment in the context of the COVID-19 pandemic, which hit the world in 2020. During her interview, Vera specified that, although she reduced the number of activities when she worked with students, she continued to privilege joint interactions and the production of arguments. This required some changes in the interaction rules. The school Moodle platform continued to be the space where the memory of the schoolwork was preserved.

Vera's current conditions are favourable for the adoption of DTs. By contrast, Vera had stated that in the first schools where she worked, she did not employ DTs due to a lack of technological resources in the classroom. This shows how the same teacher can act in different ways according to the context in which the teacher is immersed. For this reason, guaranteeing equity of access to DTs in schools is indispensable for the achievement of a quality education that integrates DTs in the teaching and learning of school subjects for all learners.

In the current socioeconomic conditions of our country, with more than 40% of the population below the poverty line,[9] public policies for digital inclusion are absolutely indispensable to guarantee the right of access to technologies for all students in public schools, which are the ones that concentrate the poorest student

[9] Data published by the National Institute of Statistics and Census of the Argentine Republic (INDEC). Available in: https://www.indec.gob.ar/indec/web/Nivel4-Tema-4-46-152. Accessed on 19 Dec 2020.

population. The situation of inequality was aggravated by the COVID-19 pandemic. The sudden change to remote education exposed the inequity in access to DTs that was necessary for educational continuity. This shift towards distance education was detrimental to students from the most impoverished sectors of society.

Under these conditions, the integration of DTs in the classroom cannot be the exclusive responsibility of the teacher. However, when the conditions of access are guaranteed at school, it is absolutely necessary that teachers are prepared to integrate DTs in their classes, overcoming personal prejudices, and understanding access to DTs as a citizen's right. For this to happen, and in accordance with the recommendations of Ndlovu et al. (2020) or Lugo and Delgado (2020), it is essential to integrate the use of DTs into initial teacher education at an early stage.

We suggest that, through these research results, it is feasible to highlight how an initial professional development course can have an impact on how PSTs are able to both appropriate and use DTs in their practice. Within the boundaries of the reported case, it is hoped that the advances of this study can provide input for researchers, teacher educators, and curriculum developers.

Our study leaves open questions. Having investigated this particular case leads us to highlight the need of widen the horizon of the study towards: an investigation of other possible trajectories and the level of integration in the DTs in other Argentinean or Latin American educational contexts involving other teachers. For example, if the pre-condition of access to DTs in schools is not satisfied, but students have access to mobile phones, what kinds of tasks can a mathematics teacher propose to integrate such technology in the classroom? How is it possible to integrate mobile phone technologies into mathematics teacher education programmes so that teachers can later integrate them into their teaching? How can we educate mathematics teachers to be intelligent and knowledgeable users of technology such that they can integrate the applications available on a mobile phone in their teaching? These questions open new horizons for research that we look to explore in the future.

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