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Sustainability of professional development programmes to teach mathematics using technology

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The literature recommends using technology for a more effective approach to teach mathematics. To integrate technology into pedagogical practices, it is necessary to implement sustainable professional development programmes for in-service teachers. This paper researches the impact and sustainability of these programmes with in-service mathematic teachers, aiming to find out how they influence pedagogical practices, using a mixed research methodology, with qualitative and quantitative data. The results show that, at the end of the programmes, teachers reveal high levels of satisfaction with their effectiveness. However, although technology is used by most teachers, who appropriate it as a teaching tool, many teachers do not propose tasks for students to use technology in learning, which compromises the sustainability of the programmes. It was also found that the teachers' years of service is not critical for the sustainability of the programmes.

Keywords: Mathematics education, technology, professional development, sustainability.

Introduction

The literature recommends integrating digital technology into mathematics curricula to provide meaningful learning (e.g., Cai & Howson, 2013). To integrate technology into pedagogical practices, it is necessary to implement sustainable Professional Development Programmes (PDP) for in-service teachers. PDP are sustainable if they produce effects on pedagogical practices both at short and long term, which means that teachers continue to develop the proposed approach in class after participating in the PDP (Zehetmeier & Krainer, 2011).

This research focus on PDP that were implemented using *GeoGebra* and *MILAGE Learn+*. *GeoGebra* was designed to combine in a single, integrated, and easy-to-use system for learning and teaching mathematics (Hohenwarter, 2013), the functionalities of dynamic geometry with the computer algebra systems and is a rich resource that contributes to improve pedagogical practices, and meaningful learning (e.g., Weinhandl et al., 2020). In *MILAGE app* (accessed on mobile devices) students can solve problems, carry out self and peer assessment, in a process of gamification with multimedia resources (Figueiredo et. al, 2016).

The teachers' professional development (PD) is a non-homogeneous and irregular process, which takes place throughout their career, and should be considered in the characteristics and events of each career phase (Huberman, 2000). In Portugal, teachers attend PDP regularly with an impact on career progression. However, several references indicate that PDP are not having the expected results in terms of using the full potential of technologies (e.g., Felizardo, 2019).

In our research, we study the impact and sustainability of the PDP implemented, aiming to understand how they influence pedagogical practices; and whether the teachers' career stage is critical for its sustainability. In this regard, we propose the following research questions: Are the PDP sustainable? Does teachers' years of service influence the sustainability of the PDP?

Theoretical background

This section is organized in three subsections from stages in teachers' careers, that we used in the data analysis, TPACK (Technological Pedagogical and Content Knowledge) and Self-efficacy, considering the knowledge and confidence teachers must have to teach using technology, and Instrumental genesis and Orchestration, considering the importance of transforming digital applications, initially artefacts, into teaching and learning tools.

Stages in the teaching career

We consider the five stages of the teaching career defined by Huberman (2000):

- Stage 1, up to 3 years of service: time of discovery, initial enthusiasm, but also of survival, struggling against the difficulties inherent to the teaching practice.
- Stage 2, from 4 to 6 years of service: phase of stabilization, professional identification and greater mastery of competences.
- Stage 3, from 7 to 25 years of service: phase of diversification, activism and experiences, seeking to diversify teaching methods. This can be a period of reduced professional commitments, with an increased feeling of routine and tiredness.
- Stage 4, from 25 to 35 years of service: phase of serenity and acceptance of reality, with less concern about work issues and more spontaneity in the management of classes. But, also, a phase of affective distance and stagnation, with resistance to innovation and change.
- Stage 5, more than 35 years of service: phase of disinvestment, typical of the end of the career, of decreased professional commitment, with a possible focus on certain tasks only.

TPACK and self-efficacy in using ICT

Regarding the teachers' knowledge for teaching mathematics with technology, we have as a reference the TPACK model (Koehler et al., 2013), that contextualizes the intersection between knowledge in the fields of pedagogy, content and technology, providing a suitable framework for teacher training to integrate technology into pedagogical practices. Kabakci Yurdakul et al. (2012) developed the «TPACK - deep scale» to measure early career teachers' TPACK. Their results revealed that this scale is valid and reliable to measure TPACK, based on the centered component of TPACK framework (Technological Pedagogical and Content Knowledge).

In relation to self-efficacy regarding the use of technology in pedagogical practice, Kent and Giles (2017) report that “for teachers to integrate technology into teaching practice, they must consider themselves to be self-efficacious at its use” (p. 10).

Instrumental genesis and instrumental orchestration

The pedagogical practices developed in the PDP are mediated by digital tools. In this sense, both in the use of tools by teachers, in their pedagogical practice, and in its use by students, in an active

learning environment, we have as a guide the «Instrumental genesis», introduced by Rabardel (1995). This "instrumental approach" is based on the distinction between artefact and instrument and on the process of progressive transformation of the former into the latter. Trouche (2004) introduces "instrumental orchestration" to stress the need for the teacher to guide the students' instrumental genesis, referring to instrumental orchestration as the didactic configurations and the ways of exploiting these configurations. In Figure 1, these processes are schematized in the context of teaching and learning mathematics using digital technology, also at issue in this intervention.

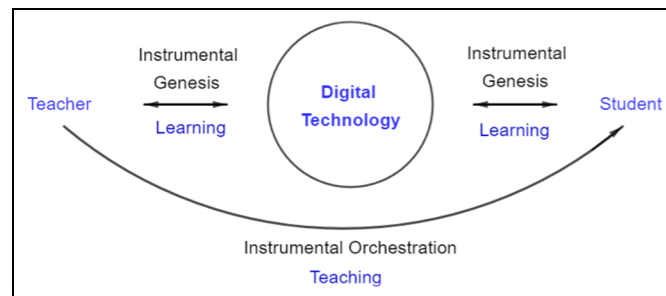


Figure 1: Instrumental genesis and orchestration in teaching and learning processes using technology (Pimenta et al., 2022, based in Rabardel, 1995, and Trouche, 2004)

Methodology

We used a mixed methodology focusing on a qualitative and interpretative paradigm (Cohen et al., 2018), complemented by quantitative methods. Thus, we frame the methodology in the «Mixed methods design», as described by Creswell (2012), in the method that defines how «Exploratory sequential design», beginning with the collection and analysis of qualitative data, complemented by the subsequent collection and analysis of quantitative data.

The participants in the study were 240 teachers who participated in the PDP and successfully completed certified training in teaching mathematics using digital technology – 76 with *GeoGebra* and 164 with *MILAGE*, which occurred from 2018 to 2021 – who also voluntarily accepted to participate in the study.

Data collection

Qualitative data resulted from document analysis, based on the trainers' reports and evaluation grids, in the end of the PDP – content analysis of the 240 teachers' critical reflection reports; analysis of the educational resources they produced within the PDP. We also collected quantitative data, using the questionnaire "[Teaching mathematics using digital technology](#)" (specifically developed as part of the research, applied more than one semester after completion of the courses and voluntarily answered online by 138 of the 240 initial participants). The questionnaire was divided into three sections: "Teaching practice using technology" (13 itens); "self-efficacy", adapted from Kent and Giles (2017) (4 items); TPACK (33 items, translated from the «TPACK deep scale», of Kabakci Yurdakul et al., 2012).

Data presentation

The distribution of the participating teachers according to their career stage (Huberman, 2000) at the date of data collection (2022) is shown in Table 1.

Table 1: Stage of participants' teaching career

Stage (Years of service)	1 (≤ 3)	2 (4 – 6)	3 (7 – 25)	4 (25, 35)	5 (>35)
Teachers (#)	0	4	77	52	5

This distribution according to teachers' years of service is representative of the respective population and is in line with data from EDUSTAT (2020), which shows that, in Portugal, the number of in-service teachers at the beginning of their career is very small (Table 2).

Table 2: Teachers' age in Portugal (2018/2019)

Years of service	< 30	30 - 39	40 - 49	50 - 59	≥ 60
Teachers (%)	1,56 %	14,78 %	36,74 %	35,08 %	11,84

Data analysis

Documental analysis

The content analysis of the teachers' critical reflection reports resulted in an assessment of the PDP, and no relevant differences were observed with reference to the stage of the teaching career. According to most of the reports, we can note that the training met the teachers' training needs, that what they learned in the training can improve their teaching practice, and that they consider that the tools they worked with have enormous potential in the educational context. Also, the evaluation of the educational resources produced by the teachers was very satisfactory, with the years of service not influencing this performance. In general, the work presented indicates adequate preparation in what concerns the implementation in the educational context of the methodologies developed. The teachers were able to explore the applications within the proposed tasks, revealing TPACK, especially technological and content knowledge (TCK) (Koehler et al., 2013). They also showed skills to design tasks to teach students, integrating TPACK, as exemplified in Figures 2, 3, 4 and 5.

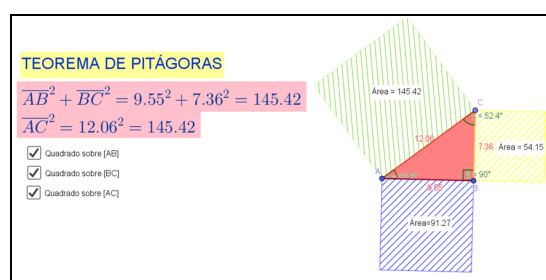


Figure 2: Dynamic construction in GeoGebra, to motivate the conjecture of the Pythagorean Theorem's statement, using dynamic text and boxes to display objects

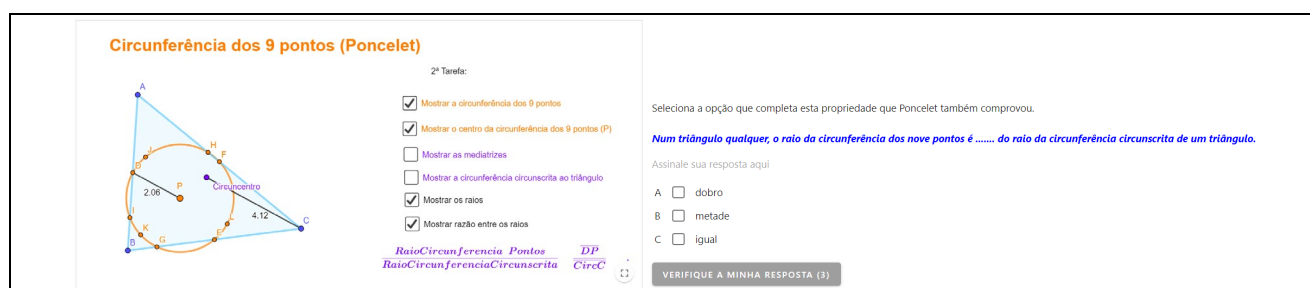


Figure 3: Proposed student task statement, using a GeoGebra applet and an interactive quiz

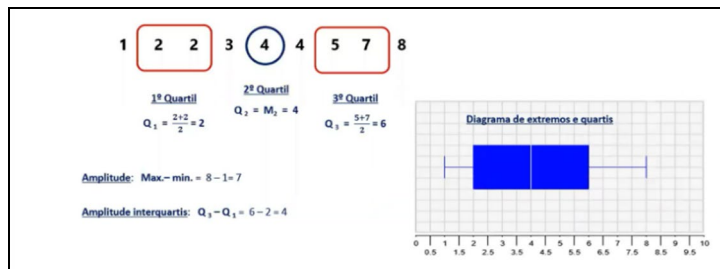


Figure 4: Capture of part of a tutorial video designed by the teacher and published on *MILAGE*

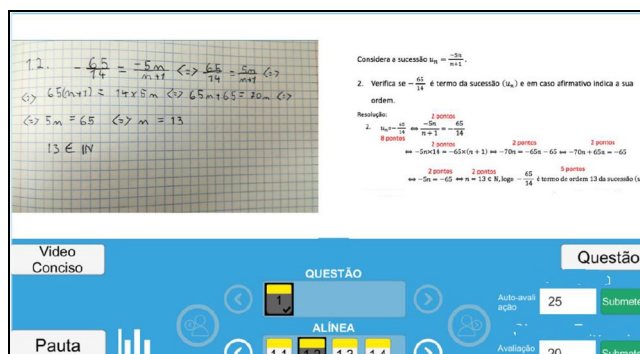


Figure 5: Resolution, self and pair evaluation, of an item published on *MILAGE* by a teacher

In Figure 2 example, the teacher mobilizes and integrates technological and content knowledge (TCK). In Figure 3, constructing and proposing the exploration of an applet and a quiz about it, teachers mobilize their TPACK. The same is illustrated in the examples of Figures 4 and 5, where teachers do not only use the content available in the application but are designers of content to teach students. These examples also show that teachers transformed the artifacts *GeoGebra* and *MILAGE* in teaching tools, towards the Instrumental genesis (Rabardel, 1995), namely to teach Algebra, Functions and Geometry (with *GeoGebra*), and practice and formative assessment of the diverse themes of Mathematics (with *MILAGE*).

Questionnaire «Teaching mathematics using technology»

The results from the questionnaires with the «TPACK deep scale» (Kabakci Yurdakul et al., 2012) and the self-efficacy (Kent & Giles, 2017), following a Likert scale (1 – “completely agree” to 5 – strongly disagree), are presented in Table 3.

Table 3: “TPACK deep scale” and “Self-efficacy” sections statistics

Section	Mean	Median	Cronbach's alpha
TPACK deep scale	3,5	4	0,96
Self-efficacy	3,27	3,5	0,85

The values obtained for Cronbach's - α of these sections allow us to consider the results reliable.

We consider the mean results obtained to be satisfactory; the median indicates that around half of them obtained a median equal to or greater than 4, which we consider to be a good global result.

The results regarding stages in the teaching career, for these two sections of the questionnaire, are shown in Figure 6. Each graph explains the global results of the participants comparing with each career stage.

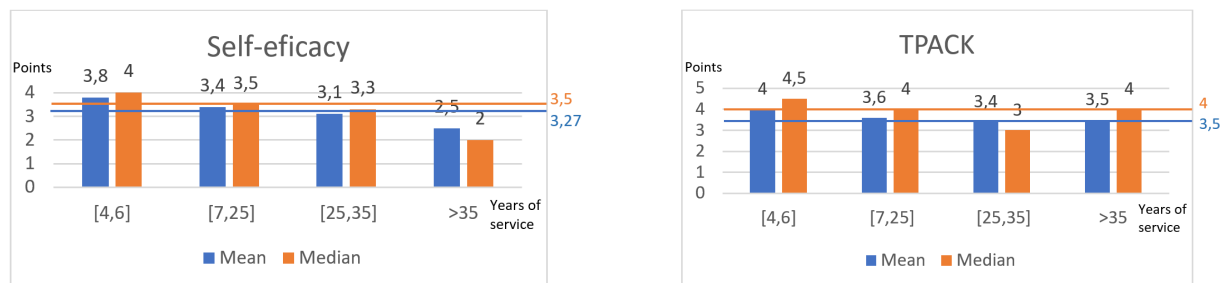


Figure 6: Self-efficacy and TPACK sections statistics by years of service

Based on the results, there is a tendency, albeit slight, for teachers with more years of service to consider themselves less confident to teach with technology. There are also slightly lower results in the self-assessment of their TPACK for using technology in teaching practice.

Regarding the application in a learning context of practices developed in the PDP (dimension “Teaching practice using technology”) the results obtained were less satisfactory, as illustrated in Table 4.

Table 4: «GeoGebra and MILAGE educational use» statistics

APP	Mean	Median	Cronbach's alpha
GeoGebra	2,15	2	0,84
MILAGE	2,54	3	0,90

Questions such as "Do your students make constructions on their devices to investigate or verify mathematical properties?" or "Do you explain mathematical properties to your students with applets presentation and exploration?" were asked, particularly designed to understand the application of specific practices developed in the trainings in the learning context. Many of the answers to these questions were "Never" or "Rarely", revealing the low applicability in context of practices for active learning using technology.

Figure 7 presents the results of the stages of the teaching career, for these two dimensions of the questionnaire.

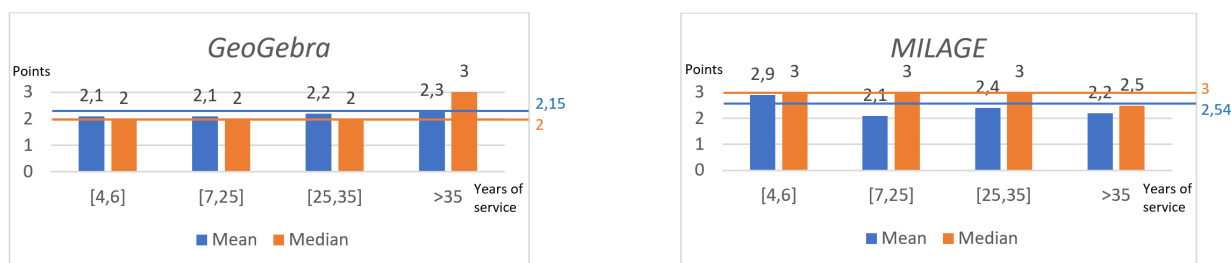


Figure 7: «GeoGebra and MILAGE educational use» sections statistics by years of service

Regarding these two subsections, particularly designed to understand the application of specific practices developed in PDP in the learning context, and even though teachers with more years of service had a lower perception of self-efficacy and knowledge within the TPACK, in teaching practice, there are no significant differences in the results at different career stages.

Discussion and final considerations

It was verified that teachers have TPACK (Koehler et al., 2013), especially TCK, to use technology to teach (Figures 2 to 5 and Table 3). Also, they feel confident to implement the practices developed in the PDP (Table 3), which underpinned the success of instrumental genesis (Rabardel, 1995), in transforming technological artefacts into teaching tools. However, few implement them with students in the context of mathematics learning. This compromises the instrumental orchestration (Trouche, 2004), as students are generally not encouraged to use these technologies as learning tools (Table 4). Therefore, there is work to be done within the technological and pedagogical knowledge (TPK) in future training courses, to move from the instrumental genesis to the instrumental orchestration (Trouche, 2004), regarding the use of technology, since, in general, students, through their teachers, do not appropriate these digital tools to learn mathematics.

Furthermore, the years of teaching service is not critical for the PDP in what concerns the integration of technology into pedagogical practices (Figure 7). If, on the one hand, teachers with more years of service consider themselves less effective (Kent & Giles, 2017) to teach with technology, and with lower levels of TPACK; on the other hand, in teaching practice, the results are similar for teachers with less time of service. In particular, using *GeoGebra* as a teaching and learning tool, in the 4th and 5th phases of the teaching career, characterized by Huberman (2000) as conservatism, stagnation and disinvestment, the results show an opposite dynamic, which can be explained by the fact that this phase is also one of serenity, resulting in part from the mastery of pedagogical practice.

So, despite the positive results obtained from the teachers' reports and from the questionnaires, it was found that few use the referred digital tools with students in the context of learning. Thus, the sustainability (Zehetmeier & Krainer, 2011) of the PDP is compromised. Also, the years of service of the participating teachers is not critical for this sustainability. Therefore, this reinforces the importance of providing teachers with PDP even for those who are at the last stage of their career.

Nevertheless, more research is still needed on how to promote the sustainability of PDP of this nature, namely to understand why these technologies have not become widespread instruments for student learning.

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