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Pre-service teachers' perspectives on the role of statistics in a learning scenario for promoting STEM integration

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This paper reports on a teacher education project aiming to prepare pre-service teachers (PTs) of mathematics and of physics for developing STEM integration activities in school. In this study we aim to analyze pre-service teachers' perspectives about the role of statistics in one interdisciplinary learning scenario to foster the integration of physics and statistics using technology, enacted with 8th grade students. Data collected from the group lesson plans and the written individual reflections of the 10 PTs enrolled in the project, qualitatively analysed, reveal that PTs of both subject areas recognize the central role of statistics in the learning scenario in relation with the three considered dimensions of the model of Authentic Integration adopted. However, they also document that the knowledge synthesis of the two areas involves a high level of complexity, and identify several challenges they faced concerning that process.

Keywords: Pre-service teachers, teacher education, statistics, STEM.

Introduction

A successful STEM integration depends on teachers' perspectives and knowledge to adopt this pedagogical practice, namely to choose effective learning materials and topics suitable for that integration and feel confident in adopting teaching methods beyond traditional ones (Kim & Bolger, 2017; Ní Ríordáin, Johnston, & Walshe, 2016). Thus, it is fundamental that, in their initial teacher education, future teachers have the opportunity to experience interdisciplinary situations to fill their lack of knowledge to develop experiences of articulation between diverse disciplines (Ní Ríordáin et al., 2016). However, in the case of mathematics, some studies show that this is the subject with less benefits in the STEM context (Becker & Parker, 2011) and that quite often mathematics is incidental to the purpose of the integration activities (Fitzallen, 2015). Emerging from a teacher education project with mathematics and physics secondary pre-service teachers (PTs), this study intends to contribute to the debate concerning the preparation of future mathematics teachers for STEM context. We formulated the following research question: what are PTs' perspectives about the role of statistics in a learning scenario with one 8th grade class fostering the integration of physics and statistics?

Theoretical framework

Pre-service teacher education on STEM integration

One of the main reasons for teachers' negative perception of STEM education is that they feel underprepared to teach within an interdisciplinary curriculum, due to the targeted scope of their own education (Frykholm & Glasson, 2005). In answer to that, several studies suggest introducing

pre-service teachers to curriculum integration during their teacher education programs by engaging them, for example, in developing STEM lesson plans as course work and including hands-on activities and inquiry-based strategies, in order to improve teacher effectiveness and confidence (Kim & Bolger 2017; Koirala & Bowman, 2003). The results of prior studies (e.g. Kim & Bolger, 2017) have shown that the experience of developing STEM lesson plans within the methods course had a positive influence on elementary prospective teachers' attitudes toward STEM. Specifically, the authors saw significant gain on: subject awareness; prospective teachers' perceived ability to create materials for STEM education, confidence and commitment to enact such lessons in their future classroom; their perception of the potential of integration for helping students learn in a fun and interesting way that makes learning meaningful, allowing them to see the connection between science and mathematics and its use in their lives; their perception of the necessity for using team work to accomplish that integration. Other studies (Koirala & Bowman, 2003; Ní Riordan et al., 2016) reported on how PTs viewed the challenges and benefits of firsthand experience developing STEM lesson plans. Many preservice teachers appreciated the emphasis on integration used in the course, which develop their understanding of key aspects of practice that need to be taken into consideration when planning such type of initiatives.

Despite the benefits of engaging PTs in STEM lesson planning within teacher education courses, this is a challenging activity as most of the teachers are unsure of the extent of individual topics that could be integrated within their lesson plans and of the breadth in their own content knowledge needed for teaching in multiple subject areas, due to their limited understanding of both science and mathematics concepts they are expected to teach (Brown & Bogiages, 2019). The same authors emphasized that, in order to be effective on mathematics and science integration, mathematics teachers need to be aware of the potential of science to provide meaningful contexts within which to set, for example, statistical investigations. Similarly, science teachers, who are developing methods for implementing investigations and scientific argumentation in their classrooms, need to be aware of the close ties of statistical tools with decision-making.

To explore authentic integration of science and mathematics, various authors suggest collaboration between mathematics teachers and science teachers as a way to develop their content and pedagogical content knowledge (Frykholm & Glasson, 2005). Though in many teacher education programs prospective mathematics and science teachers get to attend some pedagogy courses together, it is not usual having them discussing interdisciplinary issues of both scientific areas or cooperating in interdisciplinary projects, foreseeing their future teaching practice.

The model of “Authentic Integration”

Research has suggested diverse pedagogical approaches to meet the specific needs in the integration of mathematics and science in classrooms. Such suggestions offer important elements regarding the nature of the lessons that would provide opportunities to students to experience the recognized benefits of integrating mathematics and science. Several studies recommend that the lessons content should be contextualized and taught in an authentic manner involving hands-on, group work, inquiry, and discussion (Frykholm & Glasson, 2005; Treacy & O'Donoghue, 2014). Based on research, Treacy and O'Donoghue (2014) developed a teaching model for integrating mathematics

and science entitled “Authentic Integration” that is rooted in constructivism and requires lessons to be based on rich tasks, which relates to the real world and ensure that group work, inquiry and discussions play a central role in the classroom. The model embodies four characteristics that are considered to be fundamental for allowing that integration. The first characteristic – *knowledge development, synthesis and application* – is related to the integration of knowledge from diverse fields of Mathematics and Sciences, in which students must be able to apply knowledge of both areas to solve a problem in a real context. Another key feature of the integration model is *focused inquiry, as a means of enabling students to develop higher-level thinking* processes. Inquiry, in this study, it is understood as the work around multifaceted tasks that involve in an active way students in: making observations, posing questions, searching in diverse sources of information, planning research, reviewing what is already known about the experiment, using tools to analyze and interpret data, exploring, making predictions to answer the question, and communicating the results (Lederman, 2006). In this type of activity, students are encouraged to use evidence to answer questions and develop their arguments by linking them to scientific knowledge (Lederman, 2006). This kind of activities place students at the center of their learning, promote understanding of phenomena, support argumentation and communication, as well as their reasoning processes and critical thinking (Carlson, Humphrey, & Reinhardt, 2003). Another characteristic of the model is its *application to real-world scenarios*, allowing students to solve problems related to everyday life and to better understand phenomena that are familiar to them. Finally, the model requires lessons to be based on rich tasks, that is, these must *entail challenges based on problems that are transdisciplinary*. This model has proven to be effective in sense that, when the Authentic Instruction model was applied in the classroom, the learning which took place was relevant (Treacy & O’Donoghue, 2014).

Context and methods

This study is based on an innovative preservice teacher education project aiming to assist 10 Portuguese prospective teachers, enrolled in the first year of master’s programs in the teaching of Mathematics (n=6) and of Physics and Chemistry (n=4) at middle and secondary school levels, in developing knowledge about how to develop integrated STEM activities in school. The project involved one Didactics of Mathematics course and one Practical Preparation course of each program and was developed collaboratively by three teacher educators (the authors) who were responsible for co-teaching these courses. The Didactics of Mathematics course used an inquiry based pedagogical approach with a focus on pedagogical content knowledge to facilitate effective mathematics teaching and to help PTs to understand how to appropriately engage children in learning mathematics, particularly statistics. During one semester, the PTs attended the Practical Preparation courses together, having the opportunity to discuss interdisciplinary issues in these scientific areas and to cooperate among them (working in interdisciplinary small groups of three or four) in planning and enacting an interdisciplinary learning scenario. This learning scenario included a sequence of three lessons to be taught with one 8th grade low achievers class, based on a perspective of articulation of the two scientific areas, around an inquiry task (Thaw in Alaska) using technology. The task was created by the teacher educators in collaboration with the PTs and physics cooperating teacher of the class, aiming to promote students’ understanding of the physical

phenomenon of ice breaking by integrating statistical and physical concepts, and working autonomous and collaboratively. The context of the task is realistic as it is based on a contest that occurs every year in Nenana city, Alaska (*Nenana Ice Classic* – www.nenanaakiceclassic.com). The task asks 8th grade students to formulate conjectures on the most probable day of the year and moment of the day to occur the river's thaw, based on statistical data over the last 100 years that were available and explored by them using *TinkerPlots*TM software (Konold & Miller, 2005). Simultaneously, these students were required to use their knowledge from physics, to interpret the icebreaking phenomenon in that river and to give scientific arguments that could explain the moment when it occurs. Therefore, this inquiry task motivates students to mobilize and connect knowledge from statistics and physics.

For this study we collected the group lesson plans and the individual assignments of the 10 PTs (mentioned by fictitious names) written after they taught the planned lessons to the 8th grade class, where they were asked to reflect about their experience of planning and enacting the learning scenario in school. The qualitative data analysis carried out focuses on three dimensions of the Authentic Integration model: *application to real-world scenarios*, *high order thinking processes*; and *knowledge development, synthesis and application*. For data analyses purpose we searched in the PTs' individual assignments for instances where they explicitly mention elements concerning statistics present in the task or in students' intended or actual activity with the task, for each of the three dimensions of the model. Additionally we read all lesson plans as complementary information to the PTs' written reflections.

Results

Application to real-world scenarios

There is a shared recognition on part of these PTs that the task has a strong connection with a real-world scenario. For instance, the PTs value the fact that the situation proposed to students is related to a contest that actually occurs every year. The learning scenario is seen by the PTs as an opportunity for showing students that the statistics and physics they learn at school can be applicable to real life. From the point of view of some PTs, and due to its interdisciplinary nature, the task helps students to perceive that concepts of these two areas are not “only vague concepts and useless in the real world” (Elsa).

The specific role of statistics in the task, in relation to its context, is also recognized by the PTs. The fact that students are asked to analyse real world data is seen as an opportunity to develop new knowledge about the world and not just something they have to do to give an answer to the questions included in the task:

This task gave students the opportunity to develop their knowledge about the real meaning of statistical data and also about physical processes that occur in nature (...); this allows students to gain knowledge about the tangible world. (Carlota)

Some PTs also mention that students can explore a large amount of data by using *Tinkerplots* software, which contributes to a deeper understanding of the situation. The software potentiality to help students in the interpretation of data and to establish relationship with the real-world situation

is highlighted by some PTs: “[The software] by facilitating the interpretation of the data allows students to draw better conclusions about them and also to assign more meaning to them in the context in which they belong” (Daniela). Therefore they acknowledge the centrality of statistics in the task by the exploration students are asked to do of real data.

An aspect that is less mentioned by PTs is that the learning carried out around a real context, in this case a contest, can be mobilized in other situations. However, one of these PTs mentions that students may face challenges in the future:

that require skills and competences developed here. In fact, it is important to have the capacity to look at data and to observe how they can provide important information for future challenges, as the students looked at provided data and tried to understand how they could help them make the best bet. (Madalena)

High order thinking processes

During the work carried out in designing the learning scenario with the PTs, the teacher educators emphasized the intention that students could be involved in inquiry processes. Therefore, it is not surprising that, in their reflections, PTs’ classify the task as an inquiry and describe some high order thinking processes related to statistics present in students’ activity, such as, to make predictions and conjectures, explore and interpret data and draw conclusions, and present scientific arguments and counter-arguments. For instance, one PT recognizes several processes according to the different parts of the task as they had different features:

if an inquiry perspective is adopted for the task; in the section “My idea is ...” students have to formulate hypothesis and to investigate the veracity of these hypotheses by integrating the technology (in the section “The data collected indicate that ...”), and finally to draw conclusions, communicate the results obtained and justify them on the basis of their investigations. (Carlota)

As PTs reflect about students’ work with statistics around the exploration of data with the software, they describe high order statistical processes fostered by the task always in that context. They recognise that technology has a central role in supporting students in analysing variables in different representations to draw conclusions:

The study of the variables related to the moment of day and moment of month (...) allows clarifying the analysis done, and promotes not only a greater diversity of graphical representations and the consequent development of the capacities of reading and graphic interpretation, as well as a deepening of the conclusions obtained from these. (Madalena)

Some PTs also recognize the important role of technology in association with the inquiry task to promote other thinking processes such as interpretation and reflection: “Technology allows differentiated contact with statistics and learning is promoted by the fact that the task requires students’ interpretation and reflection and not only a mechanical work” (Elsa). By highlighting these processes, these PTs show that they ascribe an important and central role to statistics in the learning scenario.

The experience of task enactment in the classroom made it possible to recognize that the involved processes are very demanding for many students. PTs relate the difficulties they have noticed in

students both with their knowledge of mathematics and physics and their unfamiliarity with this type of proposal. For example, one PT mentioned that:

the students also showed some difficulties in being able to justify their ideas (...) and to present a scientific justification for the conclusions written from the analysis of the data, using the technological resource. (Cristina)

Also the software's potentiality of generating multiple representations has represented a difficulty for students, as they have to find out the representations that best support them in interpreting the data and drawing conclusions.

Knowledge development, synthesis and application

Within the learning scenario that has been designed there was no intention of teaching new topics in statistics or physics but to create a situation where students could mobilise their knowledge from those two subjects to support their thinking. PTs seem to have well understood that perspective and as such they have identified certain statistical topics in students' activity with the task, such as treatment and analysis of data, measures of central tendency or the concept of probability. This last concept has been mentioned by one of the Physics PTs, which is something interesting in this context: "By analyzing the students' answers, it is possible to verify that there are students who have managed to apprehend the probabilistic meaning [of the required answer] when they refer *at 15h it will be more likely to occur the thaw*" (Micaela).

The knowledge synthesis of the two areas is a key aspect in the adopted model of "authentic integration" but at the same time it encompasses a high level of complexity. When reflecting on the planning of these lessons, the PTs recognize that they haven't given the necessary attention to this process in order to support students:

I also stress the [students'] difficulty in relating the data obtained in *TinkerPlots* with the physical explanation. Some students had a tendency to respond that the temperature was responsible for the thaw, however, they did not relate the months obtained in *TinkerPlots* and the particular case of Nenana [river]. (António)

Some PTs point out the structure of the task as a limitation but also their planning and enactment of these lessons, where they could have promoted a systematization of ideas in order to help student to make connections between the reasoning they have developed within each of the two scientific areas. In fact, some PTs recognize they have conducted the whole class discussion of students' work in a way that did not provoke the intended knowledge synthesis:

We also failed in the discussion moment as we did not make a projection [to the whole class] of the students' solutions using *TinkerPlots* (...) that would have allowed debating in depth the topic of central tendency measures and (...) to give a scientific explanation for the obtained results. (Matilde)

Additionally, PTs have admitted that has been quite challenging to them to work with topics from the other subject. Their content knowledge preparation in only one of the areas was also felt by some of them as a constraint to be able to promote the synthesis of knowledge:

there is no doubt that it is a big challenge to integrate the two subjects in a single task, as during our academic trajectory we only had contact with the design of tasks that only making use of mathematics. (Cristina)

However, every PT mention the opportunity to work in small groups with colleagues from the other area which represented from their point of view an essential contribution to design and enact the learning scenario in the classroom: “some statistical concepts that I could no longer remember, the colleagues in my group helped me to remember them, and I tried to help them with some physical concepts that would be necessary to solve the task” (Carlos).

Conclusions

The design and enactment of a learning scenario within statistics and physics, adopting the model of “authentic integration” (Treacy & O’Donoghue, 2014), has proven to be an opportunity for these PTs to acquire real experience of STEM practice, which they highly value. When reflecting on this one semester experience, PTs show an awareness of the role of statistics in different activities that have been carried out in relation with the three considered dimensions of the model. In opposition to other studies where mathematics tends to be incidental to the STEM context (Fitzallen, 2015), both groups of PTs in this study considered that statistics assumes great centrality in the learning scenario that has been developed. One reason for the recognized visibility of statistics may be related to the features of the task itself as it requires students to analyse real world data (the 1st dimension considered in the model). These PTs highly value this dimension of the task in the sense of making learning meaningful and showing the usefulness of statistics (and also physics) to students, results also present in the study by Kim and Bolger (2017).

PTs also perceive that the task demanded high order thinking processes (the 2nd dimension) that were supported by statistics. The inquiry nature of the task required the exploration and interpretation of statistical data in order to make conjectures and draw conclusions, something that put into evidence the role of statistical tools for decision-making in STEM contexts (Brown & Bogiages, 2019). PTs also stress the important role of technology for promoting inquiry processes (Lederman, 2006), in this case with the statistical software.

From the formative point of view, it is also relevant that PTs show a critical stance regarding the effective opportunities provided for knowledge synthesis of the two subject areas (part of the 3rd dimension). Acknowledging that this process involves a high level of complexity, PTs recognize the challenges they faced and the need to give particular attention to this aspect when planning the lessons (Koirala & Bowman, 2003; Ní Riordan et al., 2016).

This study shows the feasibility of developing an interdisciplinary learning scenario in a pre-service teacher education program with two distinct areas, using a specific model. However, as this is a time consuming activity in its different aspects (Brown & Bogiages, 2019), from designing the task to the elaboration of the lesson plan, it needs to be reflected when designing the courses. Collaboration among peers from two different subject areas has revealed to be quite beneficial for these PTs and of significance in supporting an integrative approach to teaching mathematics and physics. Therefore the model of “authentic integration” seems to be adequate to support teachers from diverse subjects to work together in a STEM context.

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