TENSIONS WHEN TEACHING THE INVESTIGATIVE CYCLE IN PRE-SERVICE TEACHER EDUCATION

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We report a self-study of two mathematics teacher educators and one critical friend that studied the tensions emerging when teaching pre-service teachers the Investigative Cycle (IC) as a statistical-related process and a teaching statistics and probability framework. The focus on teacher educators is fundamental to adequately address the statistics education challenges that appear during pre-service teacher education. In this case, the more salient tensions were related to the pre-service teachers' perceptions, that considered a lack of articulation between the IC and the curriculum (Theoretical-curricular tension), were not able to concretely connect the curriculum and a concrete statistical project (Curricular-practical tension) and perceived that the IC was not applicable to real school classrooms (Theoretical-practical tension). These results suggest some solutions to improve the use of the IC in teaching statistics and probability in the school.

INTRODUCTION

The Investigative Cycle (IC) is one component that describes statistical thinking. Diverse authors and institutions promote the transition to see statistics as a process motivated by a research question that is answered with data. This provides a more authentic and motivating learning experience. For example, the Guidelines for Assessment and Instruction in Statistics Education: A Pre-K–12 Curriculum Framework emphasizes the fundamental role of the IC in statistics education (Bargagliotti et al., 2021). Several proposals regarding the IC components that emphasize different aspects of the cycle exist. For instance, Wild and Pfannkuch (1999) proposed the PPDAC (Problem - Plan - Data - Analysis - Conclusions) that highlights the IC's cycling nature and specifies the task associated with each step. Tintle and colleagues (2020, p. 4) propose a cycle highlighting statistical inference's logic and scope. Bargagliotti and colleagues (2021) propose a cycle that highlights the possibility of returning to different cycle steps. Ubilla (2021), using student productions, proposes a cycle that includes a reflection stage. In this study, we consider the different approaches of the IC, acknowledging a flexible perspective regarding the IC. In the Chilean context, the Standards for Pre-service Teacher Training (2021) consider the IC crucial knowledge. They propose that teachers must promote with their students the implementation of statistical investigations, including data collection, data analysis, inferences, and conclusion processes.

However, even though diverse international and national sources acknowledge the relevance of the IC, its use in the teaching of statistics keeps having challenges, a natural place to address this issue is initial teacher education. Recent evidence shows that applying and analyzing the IC with pre-service teachers offers opportunities to enlarge and deepen their perspective regarding statistical projects, for example, promoting the posing of different types of research questions and using several types of statistical tools (Ubilla & Gorgorió, 2022). In this context, it is fundamental to open the university classroom to see what mathematics teacher educators are doing to promote the IC, considering their fundamental role in future teachers' development. In their review, Schuck and Brandenburg (2020) identified four challenges that mathematics teacher educators face: 1) the need to question the beliefs that students hold about teaching and learning mathematics; 2) the teaching practices and methodologies that allow these beliefs to be challenged; 3) the congruence between trainers' teaching beliefs and their relationship to the teaching practices they adopt; and 4) the methods employed by the educators themselves to question their own beliefs. In addition, they also identified a lack of research regarding pedagogical content knowledge (PCK) and mathematical knowledge for teaching (MKT); this knowledge is directly related with the challenges that mathematics teacher educators face.

An essential reference is the experience of Heaton and Mickelson (2002). These authors did not explicitly research tensions in teaching statistics. However, their findings showed that they faced many unexpected challenges. One of them was aligning statistics with the curriculum and developing

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statistical knowledge among their students. In a more recent study, tensions were identified when teaching statistical inference to future teachers (Giaconi et al., 2022). These tensions are related to three dimensions: disciplinary-related statistics, teaching statistics, and students' learning statistics. These results are similar to the disciplinary tensions in the statistical domain described by Burrill and Biehler (2011). Identifying the tensions that mathematics teacher educators address when teaching statistics and how to teach statistics is necessary to improve teacher education (Berry, 2007). Teacher educators often work alone and do not socialize their conflicts they face, making it challenging to address these issues appropriately and advance statistical teacher education.

Based on the above, in this research, we propose to identify the tensions experienced by two teacher educators in an undergraduate mathematics education course for pre-service teachers focused on the investigative cycle. The following research question guides this study: What are the central tensions faced by two mathematics teacher educators when they collaboratively teach statistics and probability using the investigative cycle?

METHODS

The research consisted in a self-study developed by two teacher educators (TE1 and TE2) working in co-teaching and one critical friend. The context was an undergraduate course focused on teaching statistics and probability. The course was implemented in the last semester of a 5-year undergraduate program for future mathematics teachers during the year 2022. The participants of the course were nine pre-service teachers who already had three disciplinary courses on statistics and probability and one course regarding teaching statistics and probability.

Self-based methodologies are currently used in teacher education to understand and improve teacher educator practices (Pithouse-Morgan, 2022; Suazo-Flores et al., 2023). A typical framework in this research method is the presence of a critical friend, defined as "one who acts as a mirror to the practitioner, who raises questions about practice, and who offers constructive feedback" (Schuck & Brandenburg, 2020). Another relevant characteristic of self-studies is using different sources of information to study teacher educators' practices (LaBoskey, 2004). In this case, the course was developed in a co-teaching mode by the two teacher educators. Data were collected through recorded planning meetings and WhatsApp messages to coordinate the course implementation. which was transcribed fully in preparation for analysis. . The discourse of the two teacher educators was inductively analyzed through thematic analysis to identify the tensions around teaching the IC and teaching statistics and probability using the IC (Braun & Clarke, 2006).

Context: A IC focused course for pre-service teachers

The course was one of the two elective courses regarding teaching and learning mathematics offered in the last year at the mathematics teacher education program. It was designed and implemented for the first time and considered pre-service teachers' reported need to improve their readiness to teach statistics and probability. The course was composed of three units:

- Unit 1: This unit was focused on the IC as a fundamental tool for teaching statistics and probability. It included first a theoretical discussion of several types of ICs and the posing of research questions and interrogation questions during the IC implementation based on Arnold and Franklin (2021) and studying the role of the IC in the Chilean school curriculum.
  An example of a question worked in a course assignment was: *What are the advantages and disadvantages of each of the investigative cycles?*
- Unit 2: The main goal of this unit was to develop an actual statistical project, transiting through all the phases of the IC. The project was linked to a learning goal of the Chilean school curriculum from the statistics and probability content area. When the project was finished, pre-service teachers had to develop a pedagogical analysis regarding the implementation of the project in a real school classroom, defining suggestions for a potential teacher that could use their project. The suggestions included defining pertinent questions that the teacher could do to facilitate their students' transition through the IC and typical errors and a proposal of its addressing. An example of an activity developed in a course assignment was:
  1. *Choose a learning objective (LO) associated with probability topics.*
  2. *Define a research question that allows working with the selected LO*

3. Make a plan for the development of the investigative cycle and anticipate interrogation questions.

- Unit 3: This unit was related to topics in statistics and probability that were challenging for future teachers (combinatorics and statistical inference).

RESULTS

The central tensions identified refer to the perception by pre-service teachers of the IC. The implemented course proposed that the IC could be used to teach different statistical and probabilistic concepts with the framework of a research question. However, during the course, the pre-service teachers continuously communicated to the teacher educators their conflicts with the IC as a tool for teaching. From the thematic analysis, the tensions perceived by the teacher educators from the interaction with these conflicts were classified into three groups

Theoretical-curricular tensions

Most of the pre-service teachers perceived the non-explicit presence of IC in the national curriculum. This was continuously socialized with the teacher educators, who agreed with the pre-service teachers. This is illustrated in the following quote

They told me that the elective was not being what they expected. That they could not connect what we were seeing with the curriculum. [TE1, WhatsApp conversation]

To better exemplify, in the following quote, the teacher educators discussed how the IC is presented in the school statistical optative for grades 11th and 12th. This school course includes advanced contents in statistics and probability, such as, statistical inference and random variable models (Ministerio de Educación, 2019).

[TE1] (...) I don't know how much of that is present in the school statistical optative, because [...] it is still focused on graphic representations, which is reading and interpretation (...).

[TE2] Also Fran, the school statistical optative is not so well articulated. [...] They only work the test of the one average and I find it very difficult, it bothers me to start teaching that test because you never ask yourself that question, you can find examples, but the natural thing is to compare two averages, that is what one is always comparing, as of two different groups, but that is no longer there, there is purely that of one group. [Planning meeting]

Curricular-practical tension

Another tension is the disconnection between the learning objectives of school curriculum and the design of statistical projects in the context of the course assignments. In the second unit of the course, the pre-service teachers were asked to propose and develop a statistical project that allows them to work in a specific learning goal of the Chilean school curriculum. For example, a learning goal from 8th grade is (Ministerio de Educación, 2015):

Learning goal Number 16:
Evaluating the way the data is presented:

- *Comparing information from the same data represented in different types of graphs to determine strengths and weaknesses of each.*
- *Representing them with diagrams, including the box plot, manually and/or with educational software.*
- *Detecting manipulations of graphs to represent data.*

A tension appeared because in the proposed projects, the pre-service teachers could not correctly connect the statistical projects with the learning goals. Being able to do this was fundamental to

promoting the use of the IC in their future school classrooms, where achieving the curriculum learning goals is mandatory. This is illustrated in the following dialogue

[TE1] (…) what I see in this assignment is that it does not address much of the assigned learning goal, you know? […]

[TE2] Yes.

[TE2] Then what we can do in the next class is that they identify what concepts and procedures are involved in that learning goal. For example, this group that works on probability needs to address the concept "what is probability" or "how is the probability of intersection, union defined", so they can make a list of key concepts, like what are the key concepts that are going to be associated with this project.

[TE2] To the learning goal or not Fran?

[TE1] Ah yes, to the learning goal.

[TE2] Because projects can be approached from many concepts.

[TE1] Because of course, this was more statistical than probabilistic, you know? So the idea would be: which concepts of the learning goal are the ones that are worked in this project, how those concepts emerge in the project, you know? So, for example, for this one, which is about the probability of the union, how can we make it emerge, how this project will allow us to teach this concept, or raise it and how it will come out as a result of this concept. So, for example, what I am going to say here is that they may have to make other types of tables, as you said, they are going to have to identify which is the event, which are, all this task has to be done because it will allow them, for example, when the student asks himself, what is the probability that it rains and it is hot, but for that you have to define those two events, do you understand? and know what corresponds. So, I think that what we can do now with the next class… and it is okey if we take three more classes, it doesn't matter, we do it… so that they can see that reflection. [Planning meeting]

Theoretical-practical tension

Pre-service teachers perceived the impossibility of applying this way of teaching statistics in the Chilean school classroom. This was communicated to the teacher educators, who tried to react to this vision. Their critics focused on the disconnection of the IC with the school curriculum and the impossibility of implementing it in real Chilean classrooms, where barriers associated with the lack of access to technology and students' low motivation were considered as unbreakable. Also, pre-service teachers expected explicit procedures to teach statistics and probability and considered the IC too complex. These perceptions were addressed by the teacher educators with limited success, as can be seen in the following comment.

I tried to tell them that […] they had to understand that the research cycle was a structure to organize the class and that it could be applied to descriptive statistics, inference and probability. They told me no, that they expected to have specific pedagogical strategies to teach probability above all. They go on a lot about teaching probability. [TE2, WhatsApp conversation, 06/09/2022]

CONCLUSION

The tensions perceived/experienced by the mathematics teacher educators are related to the interaction between the course design and implementation, the Chilean curriculum, pre-service teachers

previous knowledge, pre-service teachers experiences in real school classrooms and expectations regarding how they should learn to teach.

On the one hand, pre-service teachers explicitly criticized the course proposal of using the IC as a central tool to teach statistics and probability. On the other hand, the perception of lack of articulation of the IC in the Chilean curriculum is shared by pre-service teachers and teacher educators. Learning goals related to statistics and probability are presented isolated from a complete inquiry process.

The complex set of factors impacting the tensions experienced by teacher educators can be addressed at different levels. The broadest level is the political one, where the Chilean curriculum could address the teaching of statistics from a more articulated perspective, for example, as proposed in the GAISE guide (Bargagliotti et al., 2021). However, this level is under little or null control by teacher educators. As a result, we consider as practical implications actions at the classroom level:

1. In order to promote the use of the IC with pre-service teachers, a stronger and more situated argument for its potentiality for teaching should be made. For example, showing examples of successful implementations in classrooms similar to the ones they will face in the future and concrete solutions to articulate the IC and the school curriculum.
2. The flexibility and the different possible implementations of the IC should be explicitly addressed. For example, working on a project where various statistical analyses are already done and the student's task is choosing and interpreting the proper analysis for their research question. In this case, there is no need for statistical software, which may be a constraint in some schools. Another example is noticing that focusing more on specific cycle stages is possible to work deeper on specific learning goals.
3. It is crucial to plan moments to 1) explicitly address pre-service teachers' perceptions of the statistical and probabilistics learning and teaching tools that are in question and 2) assess previous knowledge related to the learning goals considered, to provide timely treatment to their knowledge level, beliefs and concerns.

Regarding previous research, Heaton and Mickelson (2002) studied their practice as teacher educators teaching the IC. They found that students did not easily see the value of the cycle and this stresses the work of teacher educators in several dimensions. They found several challenges; among them they identified that integrating statistics into the elementary school curriculum was a more difficult task than expected. We could expect that after 20 years, the integration of the IC in the curriculum should be much easier. This, considering that the inquiry cycle has been institutionalized as a tool for teaching statistics among the scientific community (Bargagliotti et al., 2021). However, we found in this study that the challenges faced by teacher educators are very similar, even though the context of this study was different (implemented in a program for secondary teachers and placed in a Latin American country). We see, however, that currently teacher educators have more tools, for example, research literature to promote the development of the cycle as (Arnold & Franklin, 2021) or rich sources of data such as ProCivic Stats (Schiller & Engel, 2016).

Concerning the limitations of the present study, the small sample used in this research does not represent the totality of mathematics teacher educators who work in a Chilean educational context, and findings cannot be generalized. In this regard, this research is framed as an exploratory study; therefore, it is necessary to collect more data to refine and consolidate the results obtained with samples that are more representative.

More research needs to be developed on teacher educators in general and in the area of statistics and probability. This research highlights that teacher educators must reflect on their teaching practice to socialize and better address their challenges. In addition, there are other statistical investigative cycles that acknowledge and integrate the vast amount of data available, which presents new opportunities to improve statistics education and should be considered in other proposals regarding the IC and teacher education (Jaggia et al., 2020).

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