ANALYSING TENSIONS FACED BY PRE-SERVICE MATHEMATICS TEACHERS ENGAGING IN DIGITAL FABRICATION

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This article analyses tensions pre-service teachers faced during the last workshop of participation in a series of professional development workshops on digital fabrication for creating manipulatives for mathematics education. Using the concept of community of practice and the notion of tension as a theoretical framework and a qualitative research design including video recording with 5 pre-service teachers, we identified three tension categories: technological, pedagogical, and workshop design. The results indicate that tensions are often caused by conflictual decisions between the workshop designers' and students' objectives as well as difficulties in digital fabrication and its application in teaching mathematics.

INTRODUCTION

Mathematics teachers often face tensions in the teaching profession (Nipper et al., 2011). Tensions are viewed as dichotomous forces that shape the experiences of mathematics teachers and affect both their practice and professional development (Rouleau & Liljedahl, 2017). For example, tensions may occur in the context of interaction with teachers and peers, digital resources being used, or when learning the mathematics subject matter. Tensions also appear when teachers adopt new elements in their practice, such as an innovative technology or a new approach to learning. Tensions may emerge when expectation and experience do not coincide, e.g., if a pre-service teacher (PST) expects one thing and experiences another (Nipper et al., 2011).

The aim of this study is to advance knowledge on tensions that emerge when digital fabrication (DF) is introduced in a series of teacher education workshops. DF is "the process of translating a digital design developed on a computer into a physical object" (Berry et al., 2010, p. 168). Our argument for exploring tensions is that DF and its potential impact on learning cannot be studied without providing deeper insights into the role of tensions as driving forces or obstacles in teacher professional development.

THEORETICAL FRAMEWORK

In line with the research literature (Olanoff, et al., 2021; Goos, 2004), this study uses the concept of community of practice (CoP) in a pre-service teacher education context (Wenger, 1998). CoPs are characterized by tensions, conflicts, challenges, or disagreements, or what is referred to as dualities. Tensions refer to overlapping yet conflicting activities and can be forms of participation in a shared practice that is characterized by mutual engagement and joint enterprise (Wenger, 1998). As such

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tensions are a useful analytical principle to characterize participant behaviour in a CoP (Wenger, 1998).

However, there exists little research addressing what tensions emerge in a mathematics teacher education using DF as an instrument for learning and how to manage them. Moreover, most studies on DF take an individual approach to learning based on constructionism (Stigberg, 2022), which does not consider social-cultural aspects of learning, such as a group of PSTs sharing a common learning goal directed toward DF practices, in line with Wenger's ideas of joint enterprise and mutual engagement (Wenger 1998). Given this background, our research question is: What tensions are faced by pre-service teachers engaging in DF?

To address this question, the notion of "tension" in this study is not used in its everyday sense, but in a technical and specialized sense, making categorization of tensions possible. The notion of tension is used in the literature to define "difficulties, internal or external to the community, or unstable conditions, oscillating between two different and competing states that the community should address to ensure community survival over time" (Braccini, et al., 2017, p. 151). In teacher professional development, three types of emerging tensions have been identified (Nipper et al., 2011). The first type concerns the pedagogy used by the teacher. The second concerns the mathematical content, and the third one relates to digital technologies being integrated in the teaching process. Similar types of tension could be current in PSTs when they are introduced to DF.

In terms of tension categorizations in a DF context, some indicators are thus necessary to identify them as tensions. Tensions are not the same as dialectical contradictions, which are treated as inherent aspects of an activity system (Fredriksen & Hadjerrouit, 2019; Harnseth, 2008), but we argue that tensions in a CoP can be identified using similar indicators. Accordingly, tensions are defined and expressed as forces pulling in opposite directions, imbalance of participation or divergent objectives among participants, disagreement among participants, disagreement between a participant and a pedagogical approach, or imbalance in participant-tool interactions. Moreover, tensions cannot be observed directly, they can only be identified through their visible manifestations that would qualify them as tensions in terms of linguistic expressions, behaviour, actions, or signs (Fredriksen & Hadjerrouit, 2019). In other words, disturbances, disagreements, or imbalance are the visible manifestations of underlying tensions. They become recognized when participants express them in words and actions.

METHODOLOGY

Context of the study

We (two authors, together with one additional teacher educator and one DF expert) conducted four workshops, each four hours long., The participants were five PSTs, divided into two groups (group A and Group B) in their fourth year of their master's degree. The workshops aimed to introduce DF technology for creating manipulatives for mathematics teaching.

Previous research highlights that it is challenging to introduce DF through a purely design thinking approach. Georgiev et al. (2018) report that students' design results depend largely on a skill threshold as well as their previous experiences. We decided to apply a "Use-Modify-Create" as a scaffolding approach in our study (Lee et al., 2011). During the first workshop we started with finding existing manipulatives at DF platforms and learning how to fabricate those using a 3D printer or laser cutter. During the upcoming two workshops, the PSTs learned how to modify manipulatives using 2D and 3D modelling applications to appropriate them to their teaching context. In the final workshop, the goal was to create their own manipulatives and ideate on how to apply them in teaching, using the tools and techniques they learned in the previous workshops. All four workshops included activities for exploring DF technologies to create manipulatives, reflecting about mathematical concepts reified by manipulatives, and planning classroom activities.

In this study, we focus on the fourth workshop. In this workshop, the participants were asked to reflect on didactical questions about their manipulative they had started to develop in the previous workshop and to write their reflections on our common sharing platform. After doing so, they were instructed to continue to adapt their manipulatives. Group A worked with manipulatives reifying angles, and group B worked with fractions and created a container for the parts as well. Finally, they presented their manipulative in a simulated classroom context. We have chosen to focus our analysis of tensions emerging in the last workshop because we believe that the participants have acquired the best overview of technologies and how to use manipulatives in school. In the last workshop, they also work with the most amount of freedom to create their manipulatives, and by doing so, we can learn from analyzing the emerging tensions.

Data collection and analysis methods

Our approach to data analysis draws on Stouraitis et al. (2017), and Fredriksen and Hadjerrouit (2019). We use similar indicators to analyse students' expressions, views, discussions, decisions, actions, expectations, or/and choices to reveal tensions. An indicator of a tension could be based on similar criteria described in the theoretical framework on identifying tensions, such as:

a) Disagreements between the teacher and students, which may indicate a tension between learning objectives.
b) Disagreement between a participant and a method or approach to concretize a mathematical concept.
c) Imbalance in students-tool (or digital tool) interactions, challenging them when using the tool.
d) Students' disagreement on pedagogical approach and imposed mathematical learning objectives.

We use codes to describe each identified tension which relates to its manifestation (e.g., students' difficulties/ disagreements, task), and characteristics of the tension (e.g., a tension between a student and a DF method, between peers, or between students and technology). In the process of data analysis, similar tensions are classified into tension categories (TC). Accordingly, a TC is understood as a set of concrete detected tensions similar to such a degree that they can be subsumed under the same category (Fredriksen & Hadjerrouit, 2019; Stouraitis et al., 2017).

The coding of TCs was performed in several stages using an inductive-deductive approach. Firstly, we identify a set of tensions through the analysis of the video-data from the last workshop through an inductive open coding approach. Secondly, we discussed our coding and our differences and agreed on TCs. In the third final stage, we use our theoretical framework to interpret the results achieved in the second stage through a deductive approach, which lead to the identification of the TCs.

We use two data collection instruments. The first is the video recording to identify a set of tensions. Then, after the workshops, we conducted semi-structured interviews with the PSTs to clarify parts of the video data that helped us understand the rationale of their actions. Summarizing, while the classification of TCs is the result of our theoretically informed approach based on an inductive approach, the identification of tensions is a result of our efforts to interpret the TCs based on our theoretical framework through a deductive approach.

RESULTS

From the video analysis of the recordings, we could find three TCs that appear when introducing DF to PSTs: workshop design tensions, technological tensions, and pedagogical tensions. The results are chronologically presented and divided into three main sections as they emerged in the workshop.

Workshop design tensions

At the beginning of the last workshop, the students' task was to reflect on and share their work from the previous workshop by discussing and answering questions on our sharing platform. Analysis from the video recordings reveals a tension between doing the given task and modelling the manipulative they had started with the previous workshop. Group B doubted if they should do the given task or not. An example from the discussion (our translation from Norwegian to English):

Student 1: Shall we answer those things first, or?

Student 2: Hehe, maybe we can.

Student 1: Or shall we not.

At the same time, one of us teachers came to the group, unaware of the ongoing discussion, to see how they had started their work. Since one of the group members did not participate in the previous workshop, the teachers reminded the group to inform the other about the last workshop. As a result, the group decided not to do the reflection task and moved directly to show the modelled manipulative and continued to work with it. Video recordings from Group A did not reveal any sign of considering the reflection task. One of the group members had finished the manipulative at home and was eager to print it. The other group members continued where they had ended the last workshop. They found creating manipulatives more motivating than writing their thoughts about didactical considerations. They agree on the importance of the didactical reflections but prioritized modelling the manipulative.

Technological tensions

Almost right from the beginning of the workshop, the PSTs focused on modelling the manipulative. Therefore, tensions between students and DF technology were dominant. Tensions appeared in all phases of the design and production process in particular 3D modelling and preparing for printing. Participants often struggled with finding ways to model the manipulative they had in mind in 3D and using the functionality offered by the 3D modelling software. Furthermore, they had difficulties in defining the correct level of support for printing the 3D object. Tensions were often resolved through collaboration within the team and with the instructors.

Before printing, participants further edited their manipulatives, broke them in pieces and negotiated object aspects e.g., the size of the manipulative taking printing time from the slicing program explicitly into account. They tried different sizes, qualities, and designs to reduce the printing time to manage a finished manipulative during the workshop. One PST argued that a laser cutter has greater potential for school because it is much faster than a 3D printer.

Overall, participants' focus was not the same. As mentioned earlier, one participant had a nearly finished manipulative, so his main focus was preparing, printing, and assembling it. The other two participants in Group A were mainly concerned with 3D modelling the manipulative they had in mind. One of them finished modelling and attempted printing during the workshop, while the other did not attempt printing (probably due to lack of time).

There was significant interaction between participants who exchanged 3D modelling and printing knowledge with each other. One participant was most advanced in 3D modelling and assisted the other two extensively. There was also a significant exchange between participants in the group.

Pedagogical tensions

Lastly, the PSTs were instructed to share their work and demonstrate how the manipulative could be used in a classroom context. We classified tensions emerging between the student and pedagogical approaches as pedagogical. The PSTs struggled to connect the reified concept to the curriculum, e.g., they concluded that the angles are not explicitly mentioned in the curriculum. After approximately a 2 min, 30 seconds search for an appropriate competence goal in the curriculum, the group turns to the manipulative and does not attempt to relate to the curriculum anymore and focus on the manipulative's affordances. PSTs discovered different mathematical concepts that could be reified with their created manipulative, e.g., displaying different divisions of a straight 180 degrees angle, measuring angles, or demonstrating concepts of acute, right, and obtuse angles. Still, the PSTs struggled to agree on a concept and a way to present it to students. Group B planned to teach an activity with fractions, which did not depend on the manipulative they made. Instead, the manipulative was used as a supplement and a catalyst for cooperation and discussion. One participant mentioned that dynamic mathematical software, e.g., Geogebra, could be used instead. Group B was spending the majority of the time on creating a container for the fraction parts, arguing that a box for all components is essential in a school context. However, when doing so, time spent on the box was prioritized. Neither the mathematical concept nor planning for a demonstration on how the manipulative could be used in school was prioritized.

DISCUSSION AND CONCLUSIONS

Our research question was: What tensions are faced by pre-service teachers engaging in DF? Drawing on Wenger's community of practice and the notion of tension as a theoretical framework, the aim of this study was to make a first step in identifying and analysing the tensions that emerged when PSTs engaged in DF in a series of workshops. Even though this is a work in progress, and that it is limited to one workshop of four hours, the findings of this study help to advance current knowledge in this field both from a theoretical and practical point of view.

Firstly, the theoretical framework provided useful guidance for operationalising the notion of tension, making a categorisation of tensions possible, and using indicators to identify tensions through their visible manifestations by means of linguistic expressions, behaviour, actions, or signs in a CoP setting. The framework thus provides a foundation for identifying and analysing tensions in new ways, in contrast to constructionist approaches to DF, which focus on individual construction of knowledge. Secondly, we identified three TCs: workshop design tensions, technological tensions, and pedagogical tensions in a setting and methodology that models a series of workshops that involve 5 PSTs divided in two groups, participating in DF activities as an instrument for learning mathematics didactics, focusing on manipulatives. Those tensions emerge and are closely related to each other. We could not motivate the PSTs to do the first task where they should reflect on how to reify the manipulative in a classroom context. By not doing so, we argue that pedagogical tensions emerged from what was coded as a workshop design tension. Thirdly, the introduction of DF presents many challenges. The DF technological tools were challenging for PSTs for many reasons, which relate to the lack of knowledge on how to apply DF technologies and to the minimum training spent on DF technologies and prior knowledge in using manipulatives in a school context. Given that PSTs had already participated in three workshops, the challenges associated with correctly modelling and printing 3D manipulatives appear substantial but possible to resolve within a community of teacher educators. Good foundations in both mathematics and DF technologies and their interaction are important for applying in DF in teacher education. It is important to research how the teaching and learning environment needs to be designed to ensure a smooth integration of DF and mathematics. Based on our analysis of tensions from this study, we will design new workshops for in-service teachers, and hope to produce changes DF practices, and as a consequence, changes in learning mathematics.

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