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Using teachers' research to elicit professional development among pre- and in-service mathematics teachers: a qualitative meta-analysis of mathematics education in graduate programs

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This study used qualitative meta-analysis to analyze the professional development of 38 pre-service student-teachers who conducted a qualitative study in mathematics education as part of their learning requirements. The analysis of the teacher-researchers' (TRs) studies used qualitative meta-analysis and focused on learning through activity (LTA) (Simon, 2018). Analysis was based on a meta-model that was constructed to characterize the development of the TRs according to the following parameters: skill of mathematics instruction, pedagogical perceptions, pedagogical knowledge, and problem-solving methods. In this paper, I present and discuss the meta-model study of only the last parameter (problem solving).

Keywords: Professional development, teacher researchers, qualitative meta-analysis, learning through activity (LTA), problem solving.

Introduction

Professional development programs for pre- or in-service mathematics teachers or teacher educators generally include practice in conducting research, based on the perception that the short- and long-term goals of post-secondary and graduate teacher-education programs are to develop expert teachers, and that conducting original research is one way of obtaining expertise. Most teachers in college or university programs claim that they have developed professionally, and this study examines various aspects of their professional development as a result of research that they carried out in their practical teaching environments.

Aspects examined included the structure of their research tools, task design, data analysis, interpretation of results and data, and so forth. A meta-model was developed to incorporate all these elements and more. The model describes the main categories found in the studies: problem solving, theory, beliefs and attitude, assessment, and environment and setting. In addition, the model describes the catalysts for the TRs' professional development for each category examined, describes the study tracks, and illustrates whether the TRs followed a partial or complete pathway to their goal. The elements highlighted in the model are the LTA components identified as part of the TRs' research process.

Theoretical background

The teacher as researcher

Requiring pre- or in-service teachers to engage in research as part of their practical instruction moves their education away from the educator-centered model (where the educator “communicates” information toward the student) towards a more student-centered approach, thus shifting pre-service teachers from receivers of pedagogical knowledge from “higher” authorities (i.e., the educator) into creators of such knowledge (Cochran-Smith & Lytle, 2009). Allowing pre-service teachers to conduct their own original research offers not only an instructional tool for teacher educators to engage in student-centered, problem-posing pedagogy (Souto-Manning, 2012), but also offers a tool for the pre- and in-service teachers themselves to investigate any worries or problems of practice they may have in their classrooms and schools in the future (Baumann & Duffy, 2001). Knowing how to conduct proper research will become a tool that extends beyond the teacher-education classroom, allowing in-service teachers to continue their professional development after completing their formal coursework and providing them opportunities to improve teaching and learning (Lysaker & Thompson, 2013), explore questions of influence and social justice (Fecho & Allen, 2011), change their understanding of their own students’ understanding of the various concepts (Parkison, 2009), improve their skill in intervention (Christenson et al., 2002), improve and change their beliefs, and take action appropriate to their findings. Snow-Gerono (2005) found that teacher-researchers (TRs) changed not only their classroom practices, but also their attitude towards teaching. Even small-scale research projects allow TRs to improve their understanding of the research process (Gray, 2013), their selected topic(s) of study (Goodnough, 2010), and even about themselves (Reis-Jorge, 2007).

Previous studies have found that conducting research leads teachers to professionally develop their teaching skills and to better understand their beliefs and attitudes toward themselves as teachers and toward their students/pupils as learners. In this study, I focus on teachers in the field of mathematics education. The goal was not only to examine the extent of professional development that the research project effected, but also to focus on the catalysts for development that emerged in the TRs’ research process.

Learning through activity: theoretical framework

As the facilitator of the in-service teachers’ research projects, I utilized the learning through activity (LTA) theory as a strategy to investigate my students’ professional development. The LTA theory aims to integrate conceptual learning and instructional design. With respect to mathematics, LTA research is based on the questions: How do humans learn mathematical concepts? and How can instruction be designed to enlist these learning processes? Guided by these questions, LTA researchers have examined the design of mathematical concept study units and have developed a theory that simultaneously guides the work and derives from it (Simon, Kara, Placa, & Avitzur, 2018).

As defined by some of the studies on LTA, a “mathematical concept” is a researcher’s assumption used to characterize student knowledge. It does not represent what a student might actually say about her understanding but rather provides focus with respect to the learners’ *actions* and allows

the researcher to recognize specific, higher-level actions that result when lower-level (current) actions are coordinated with the actions of the learning activity. This coordination of actions, along with explanations to understand the concepts involved and reflective abstraction, becomes the source of a newer, more advanced concept (Simon et al., 2018). Based on this definition, theory designers also have defined specific “instructional” actions and procedures that promote conceptual learning. These may include hypothetical learning trajectory (HLT), guided reinvention, specific design steps, and use of computer applications, all of which can lead to a coherent process of building mathematical concepts.

Method

Research goals

The research goals were two-fold: 1) identify and characterize dimensions and aspects related to the professional development of teachers in the role of researcher in mathematics education, and 2) identify the catalysts that lead to this professional development.

To this purpose, the research questions were as follows:

1. What characterizes the professional development of TRs in the wake of the process of research on mathematics education?
2. Under what aspects does professional development takes place? What are the catalysts for professional development?

I narrowed focus onto two specific themes: “perceptions of concepts” and “conducting instruction.”

Population

No direct population. The qualitative analysis was conducted by examining the research study projects carried out by undergraduate students. (These projects were presented as their theses). Fifty-six student studies were initially examined, but only 38 that met the three criteria – the research involved mathematics education, the findings were qualitative, and the TR’s or mentor’s journal were available – were chosen for the meta-analysis (8 teacher educators, 18 elementary school teachers, 12 high school teachers).

Meta-analysis

Meta-analysis studies act as a guide for prospective research by qualitatively analyzing studies in a specific field to comparatively identify similarities and differences between them (Çalık & Sözbilir, 2014). This present meta-analytical study is aimed at systematically analyzing in-service teacher research on a variety of subjects in mathematics education so as to identify any professional development that occurred thereby and to determine any deficiencies and gaps therein.

Data analysis

The research process involved hermeneutic and dialectic aspects: hermeneutic to do justice to the original primary findings and dialectic to compare and contrast them with each other.

The first stage consisted of an initial reading of all the papers to familiarize myself with the subjects, methods, data analyses, findings, and results of each study. Next, at the second stage I formulated sub-questions that I attempted to answer during rereading. They were: What

characterizes the topics that teachers choose to study? What do teachers ask in studies about student learning? What do teacher educators ask about their associate teachers? What do teachers ask about themselves? What characterizes the process by which teachers build the research structure? What do teachers learn from the definition of intervention principles? How do teachers analyze data as researchers? Where and for what reason do teachers note in their work or journals the difference between being teachers and being researchers? Do teachers eventually indicate changes in their perceptions or beliefs?

In the third stage, I constructed a number of meta-models based on the answers to the above questions. These included meta-models pertaining to research subjects and populations, classification of research questions and research methods, application of theories, and the TR's skills and perception of mathematics instruction.

In the fourth stage, the meta-model was expanded based on LTA theory so as to recognize which TR actions complied with the theoretical predictions. The categories that evolved were "problem solving," "theory," "beliefs & attitudes," "assessment," and "surroundings". At this stage, I built the framework of the expanded model. I chose random events from the studies and examined them based on the categories in the extended model and, as a result, was able to refine the model.

Triangulation

I supplemented the qualitative meta-analysis with three types of data: the final versions of the papers the TRs submitted, the journals they submitted to me, and the notes that I, as facilitator, wrote throughout the procedure.

Findings

The meta-models constructed revealed five main categories that fell under "mathematics instruction, skills perceptions, and knowledge" and that involved project mechanisms unique to teachers' work in the research milieu. I then narrowed it down to the "sub-meta-model" of "problem solving" (see Figure 1 as part of an entire model) to provide a detailed analysis of the professional development of the TRs as it occurred during the research process.

Meta-model research: mathematics instruction, skills perception, and knowledge

As mentioned above, all the studies chosen for analysis included some form of "conceptual learning" and "instruction" and could be described through meta-model analysis. All the categories and subcategories in the meta-model can be divided into actions, thoughts, perceptions, or catalysts, and the four categories that pertain to the LTA instructional design framework. In constructing the meta-model, I analyzed events and attempted to identify these four components (shaded elements, Figure 1). Thus, it was possible to identify in which cases the process of teaching and intervention promoted perception of mathematical concepts and those that did not.

Professional development in problem solving

In the meta-model, "problem-solving" includes any new action, skill, or perception of problem-solving instruction that occurred during the TRs' research. The TRs did not use standard problems from textbooks or online per se, but selected exercises or problems suitable for the topic at hand. In

addition, where changes in perception were observed, they redesigned tasks and imagined the solution their population might hypothetically give. Their design of their study tools evolved and changed if they recognized that their hypothetical path did not suit their population, as for example, they had fifth-grade material but were teaching a third-grade class (for which no appropriate problem sets were available).

Identification of catalysts

Using LTA theory helped me define and recognize the intervention processes constructed by the TRs. If I recognized them as one (or more) of the four components of instruction that promote development of a mathematical concept, I examined the events to pinpoint the elements (i.e., catalysts) that led to this development. Catalysts included the following: assessing and analyzing solutions according to personal or theoretical interpretation, research questions that focus on identifying the development of concepts or actions, research questions that focus on changing the learning environment, and teaching and intervention.

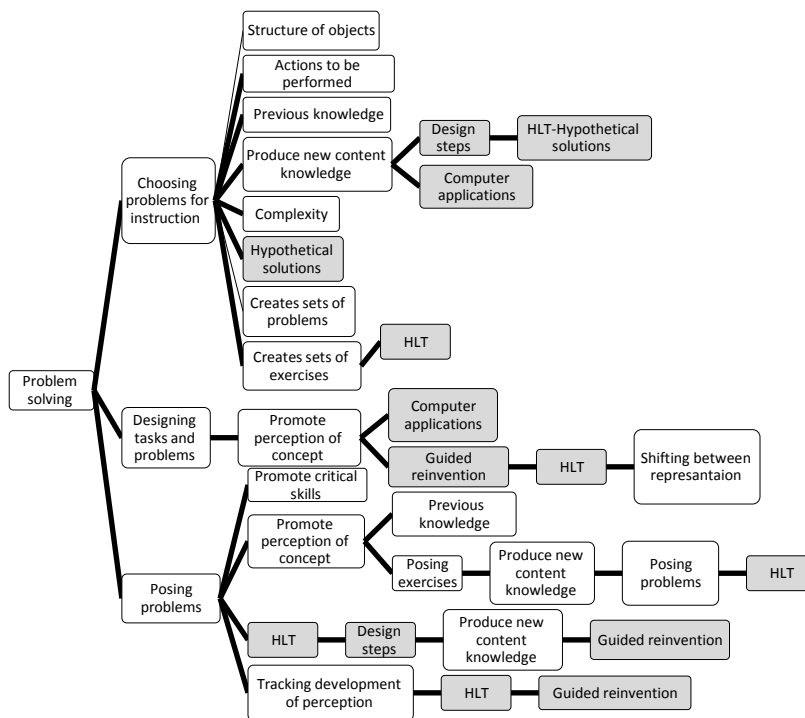


Figure 1: The “problem solving” component of the meta-model research

Below are three cases that illustrate the professional development of the TR with a focus on the catalysts.

Example 1: Designing tasks and problems to promote graphic representation

Rachel, a 12th-grade teacher, wanted to help her students solve calculus problems through graphic drawings. She found a problem online and adapted it to the non-computer environment. After analyzing the students’ solutions, she realized that her students did not yet have sufficient knowledge to solve the problem. She then chose problems from the textbook, redesigning them to encourage a graphic representation of the solution. However, she discovered that most students solved the problem algebraically; only a few applied graphic representations. She therefore proceeded to design two tasks: drawing the derivative of a given logarithmic function, and graphing

the original function of a derivative presented as a denominator. She specifically chose functions where the students would have to consider many aspects of the “derivative” concept. At this point, she wrote some hypothetical (correct and incorrect) solutions, and made a hypothetical list of aspects of perception related to the understanding of the original function and its derivative. In her journal, Rachel reflected how preparing the list of hypothetical solutions in advance helped her understand how her students might perceive the two concepts. From this stage on, Rachel worked as follows: 1) She chose a set of problems which, combined, developed understanding of the mathematical concept in the context of graphic representation and offered a multiplicity of examples and graphical solutions to problem. 2) She redesigned textbook problems to fit her research goal (fostering understanding of graphic representations of functions and shifting from one graphic representation to another). At each stage, she prepared a list of hypothetical solutions and implemented “guided reinvention”. She also posed questions to enhance her understanding of the solution process based on her analysis of each lesson.

Rachel is an example of a formative teacher who posed problems in accordance with the goal: developing a perception of graphs in calculus. LTA follow-up (HLT, guided reinvention, design steps, and computer application) enabled analysis of the stages of development and their identification. The catalyst was her investigation of the students’ solutions whereby she concluded that the original problem did not invite a graphic solution, leading her to design her own problems that focused on her research goal. By posing problems, she learned new mathematics content knowledge.

Example 2: Designing tasks and problems to promote transfer of learning

Betty, a grade-2 teacher, wanted to promote her pupils’ perception of the multiplication operation by solving problems involving tessellations. Her research goal was to promote transfer of learning from tessellation problems to multiplication problems and vice versa. Her research paper and journal indicated that she focused on the problem-solving aspect as follows: First, she found problems in the textbooks and redesigned them into a set appropriate for second graders. After analyzing her pupils’ solutions, she concluded that they understood the three basic properties of tessellation. Next, she posed tessellation problems using the categories she had created and introduced multiplication questions. At each stage, Betty wrote hypothetical solutions in advance and then analyzed the actual results to ascertain how her pupils perceived multiplication and tessellation. Also, at each stage, she focused on the dual purpose of posing problems whose solution reflects a perception of multiplication expressed through tessellations, and vice versa, which was supposed to reinforce each.

Betty’s professional development in problem solving was two-fold: 1) while posing the problems she refreshed the multiplication concept by creating different tessellations not necessarily with geometrical polygons; and 2) she considered the generic process of designing and posing problems: setting a learning goal, formulating steps to achieve it via specific concepts, posing appropriate problems, writing hypothetical solutions, analyzing the problem, and posing new problems accordingly. The catalyst was her unique study linking these two concepts and the fact that she had to design assessment rubrics to identify the development of the concepts.

Example 3: Designing tasks and problems to identify teachers' perception of division by fractions

Sofie is a teacher facilitator. Her research focused on teachers' perception of division by fraction, a concept that is sometimes confusing even to in-service teachers. She had previously experimented with the concept of the addition and subtraction of fractions, but she strongly suspected that teachers had difficulty posing problems that clearly taught the nature of division by fraction. She composed a set of division exercises illustrating different aspects of division by fractions. Her plan was to interview teachers and ask them to pose a word problem for each exercise. She believed that how the problems were formulated would reveal the teachers' perceptions. Sofie first formulated and solved a set of hypothetical problems herself to determine if her chosen exercises were suitable and if they encompassed all aspects of division by fraction. Sofie's professional development was expressed in two ways: 1) Based on theories she had learned and papers she read, she composed and recomposed the set of exercises five times until she deemed them satisfactory. (She thus showed that she had learned to compose exercises as a series so as to develop various aspects of fractional division.) 2) Sofie learned how to convert the exercise into "realistic problems" so that the concepts of dividing by fractions were reflected in the formulation of the problem. Thus, her own concept of division by fractions developed and deepened. In addition, her research led her to construct a path for teaching the subject so that her students would develop a broad, coherent perception of the action. Sofie's catalyst was her exceptional interview structure that obliged her to overhaul exercises to solve the appropriate problem. An additional catalyst was reading studies and theories regarding the understanding of division by fractions. She tried to examine the perception of teachers against the perception of students.

Discussion and implications

In this brief article, I have presented a general model of the main and sub-categories that indicate the professional development of in-service teachers who conducted research. I then elaborated on the "problem-solving" category. This present article augments previous papers that discuss similar aspects (Baumann & Duffy, 2001; Cochran-Smith & Lytle, 2009; Goodnough, 2011; Fecho & Allen, 2011; Friedrich & McKinney, 2010; Labaree, 2003; Lysaker & Thompson, 2013; Moran, 2007; Souto-Manning, 2012; Vetter, 2012).

Three major findings emerge from the analysis of these studies in which TRs were required to deal, on their own and perhaps for the first time, with formative assessment at every stage of their research, using intermittent results to (re)build and improve their research tools and intervention actions. First, it is clear that such assignments support the coherent perception of mathematical concepts and processes and support the TRs' own skills in constructing a lesson to promote the development of their own coherent perceptions. This finding is consistent with the LTA theory (Simon et al., 2018). Second, it supports the general model of the skills and actions of the TR, which illustrates the catalysts in the sub-categories. (For example, what and when do teachers learn from theory?) Identifying catalysts and understanding their role in each category may help facilitators design studies with a higher potential for enabling the professional development of the TRs. Third, enhancement of the TRs' mathematical content was a central goal (and outcome) of this study. At the outset of their projects, the TRs considered themselves quite knowledgeable about the subject

that they had decided to study, but, while building their research tools, they realized that there was a need for them to deepen their content knowledge.

Because this study was conducted using qualitative meta-analysis research, it presents a summary of findings from all the TR studies. This method is effective because it generates a comprehensive result that includes many aspects of the phenomenon (McShane, & Böckenholt, 2017). Thus, the “problem-solving” meta-model can be used to create a pathway that describes each of the studies individually. If a particular path lacks some necessary component(s), e.g., “step design” or HLT, this indicates that the TR progressed less than one who did employ all the components.

Finally, the complete model can assist the facilitator in guiding TRs in designing research structure, making sure that they include activities with the potential to develop and promote mathematical “knowledge.” A paper regarding the use of the complete model is currently in preparation.

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