Beliefs, knowledge, teaching practice: three factors affecting the quality of teacher's mathematical problem-solving

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Abstract. Teacher knowledge and beliefs are known to play crucial roles in shaping teacher teaching practice regarding mathematical problem-solving. Thus, assessing the teacher's quality of mathematical problem-solving can be traced through such three factors. This paper aimed at exploring the elements of mathematics-related beliefs, mathematics problem-solving knowledge for teaching, and problem-solving-based teaching practice needs to be improved by mathematics teachers. Some empirical findings of assessing those three factors from a two-year research project involving a total of 288 teachers from primary and secondary school on teacher's problem-solving were presented as the manifestation of teacher quality regarding mathematical problem-solving. More specifically, the teachers participating in such a research project were indicated to have beliefs about nature of mathematics, mathematics teaching and mathematics learning ranging from Instrumentalist view to problem-solving view. Also, it was found that teacher problem-solving content knowledge such as knowledge of mathematics problem and problem-solving strategies was insufficient to hold a problem-solving instruction. Furthermore, the teacher's teaching practice, assessed by observing how the teacher participants guide their students to solve a mathematics problem following Polya's four stages of problem-solving, range from directive to consultative teaching. In sum, beliefs, knowledge, and teaching practice are discussed as three interdependent factors which determine the quality of teacher’s mathematical problem-solving.

1. Introduction
Promoting problem-solving skills is known as an essential task for mathematics teachers. However, some evidence shows that there are still many teachers who do not meet the requirements to be able to apply the problem-solving approach in their class [1]. To find out the causes of these findings, experts explain the factors that influence teacher quality in implementing problem-solving [2-3]). These factors include teacher beliefs, teacher knowledge, and teacher's teaching practices themselves.

In attempting to trace these factors, some scholars have tried to conceptualise and develop models of the relationship between teacher beliefs, knowledge and teaching practices (see e.g. [3]). For example, Fennema [4] and his colleagues emphasise that the quality of classroom teaching is determined by the interaction between teacher knowledge and belief. Concerning mathematical problem solving, these interactions were then further studied by Siswono et al. [5] by observing three junior high school mathematics teachers obtaining that teacher beliefs have a substantial relationship with teacher knowledge of problem-solving. In particular, the Instrumentalist type of beliefs their studies are consistent with their insufficient knowledge of problem-solving. Meanwhile, Platonist type teacher beliefs and the beliefs of problem-solving type teachers are consistent with their knowledge of
pedagogical content and problem solving that appear to be equally enough. This paper discusses the factors affecting the success of problem-solving learning. These factors include teacher beliefs, teacher knowledge, and teacher teaching practices related to mathematical problem-solving.

2. Mathematics-related beliefs in relation to mathematical problem-solving
Beliefs are conceptualised as the personal ideologies, conceptions, world views and values that shape practice and orient knowledge of an individual. Beliefs are also considered equivalent with concepts, meanings, propositions, rules, preferences or mental images [6] On the other hand; beliefs are also viewed in a much broader understanding as mental constructs representing the codifications of individuals’ understandings and experiences [7].

Beliefs about mathematical problem solving are nearly connected to the beliefs about the nature of mathematics and mathematics teaching [8]. Viholainen, Asikainen, and Hirvonen [8] asserted that beliefs about the nature of mathematics affect beliefs about mathematical problem-solving and vice versa. In addition, beliefs about mathematics learning also signify beliefs about mathematics teaching. Meanwhile, Ernest [2] expressed that teacher views on the nature of mathematics affect how they play a role in teaching and learning in the classroom. For this reason, he categorises three different philosophical views on the nature of mathematics: instrumentalist, platonist, and problem-solving.

Table 1 summarises this categorisation, completed with relevant resources about teacher philosophical beliefs about mathematics learning and teaching.

| Nature of mathematics | Teaching Mathematics | Learning Mathematics |
|------------------------|----------------------|---------------------|
| **Instrumental**       | An instructor in the instrumental view | learning mathematics means mastering particular procedures |
| doing mathematics means finding correct answers, quickly, using the (one, correct) standard procedure | Mathematics teaching needs to be content-focused, with an emphasis on performance | A personal activity based on watching, listening and imitating until fluency is attained. |
| A given body of knowledge and standard procedures | | |
| **Platonist**          | an explainer | learning of mathematics means understanding and adopting an existing knowledge structure |
| “‘You can do a problem in different ways, but there's always going to be one answer.” | the teaching of mathematics requires to be content-focused with emphasising active understanding | An individual activity based on practical reflection and exploration. |
| The concepts, theorems and notations of mathematics are thought to be determined beforehand, and they should be acquired in the process of learning. | | |
| **Problem-solving**    | a facilitator of learning | learning of mathematics is seen as an autonomous exploration of one’s interests |
| Mathematics is seen as an active construction process. The crucial objectives of learning reasoning skills and constructing new things | the teaching of mathematics, it is the learner that needs to be in focus rather than the content | it is most consistent with the constructivist view of mathematics learning |
| An interconnected body of ideas which the teacher and the student create together through discussion | A non-linear dialogue between teacher and students and | An interpersonal activity in which students are ***
Misunderstandings are made explicit and worked on, challenged and arrive at understanding through discussion.

3. Mathematical problem-solving knowledge for teaching

In the last decade, much concern has been given by researchers and practitioners to the type of knowledge that teachers require to teach mathematics. The categories of teacher knowledge formulated by Ball, Thames, and Phelps [9], for example, have contributed significantly to the development of mathematics teacher education as one of the foundations for understanding variety of mathematical knowledge required by the teacher. In this case, Ball et al. emphasised that mathematics teachers need knowledge that is specifically not required by other professions. For example, the demand for mathematical understanding that needs to be mastered by a mathematics teacher will be different from the mathematical understanding required by a mathematician. Furthermore, Ball et al. also emphasised that mathematical abilities, in general, do not adequately reflect the knowledge and skills needed in effective mathematics learning.

Similarly, about problem-solving, Chapman [10] reveals that the knowledge needed to teach effective mathematical problem-solving should also be greater than only problem-solving ability itself. Teaching problem solving requires some understanding related to some experience. Chapman [10] mentions three types of knowledge for problem-solving: content knowledge of problem-solving, pedagogical problem-solving knowledge, and affective factors and beliefs about mathematical problem-solving. (see table 2).

Table 2 Mathematical problem-solving knowledge for teaching [10]

| Type of knowledge                  | Knowledge                              | Description                                                                                                                                 |
|-----------------------------------|----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Problem-solving content knowledge | Mathematical problem-solving proficiency| Knowledge of what is needed for successful mathematical problem-solving                                                                     |
|                                   | Mathematical problems                  | Knowledge of the nature of meaningful problems; structure and purpose of different types of problems; the effectst of problem characteristics on learners |
|                                   | Mathematical problem solving           | Being proficient in problem-solving                                                                                                         |
|                                   | Problem Posing                         | Knowledge of mathematical problem-solving as a way of thinking; problem-solving models and the meaning and use of heuristics; how to interpreting students' unusual solutions; and implications of students' different approaches |
| Pedagogical problem-solving       | Students as mathematical problem solvers| Knowledge of what a student knows can do, and is disposed to do (e.g. characteristics of good problem solvers; students’ difficulties with problem-solving; students' problem-solving thinking) |
| knowledge                         | Instructional practices for problem-solving | Knowledge of how and what it means to help students to become better problem solvers                                                              |
Affective factors and beliefs | Knowledge of nature and impact of productive and unproductive affective factors and beliefs on teaching and learning problem-solving

Table 1 portrays the categories of problem-solving knowledge for teaching into three primary categories, namely content knowledge of problem-solving, pedagogical problem-solving knowledge, and knowledge of affective factors related to problem-solving instruction. Knowledge of problem-solving content is explained as follows. Content knowledge includes four domains. First, knowledge of the meaning of the problem. In this domain, teachers are required to understand problems based on their structure and goals in order to guide students to find solutions incorporating understanding the types of tasks, such as cognitive tasks; assignments with the potential to develop mathematical creativity in problem solving; tasks that require problems that generally allow for various problem solving strategies; rich mathematics assignments, and open problem-based assignments.

Second, knowledge of mathematical problem-solving proficiency. For this, Chapman describes this category into four, namely (1) conceptual understanding of concepts, procedures and mathematical relations, (2) the understanding of heuristic strategies and specific strategies and when and how to use them in solving any mathematical problems, (3) the ability to think logically and an understanding of reflection on self-awareness, control and monitoring, as well as supervision of the cognitive itself during the process of problem solving, and (4) having beliefs in mathematics, problem-solving, and the capability to solve problems themselves that can support their beliefs and motivation.

Third, knowledge about problem-solving. This knowledge is needed for example to understand that problem solving is not only seen as a process but also as a way of thinking. Mayer and Wittrock (2006) describe this way of thinking to include both inductive and deductive reasoning, critical thinking, creative thinking, and decision making. This understanding, as Chapman revealed, influence the teacher's perspectives about figuring out the model of problem-solving processes. These problem solving models have been formulated by various experts such as Schoenfeld [11] (reading, analysis, exploration, planning, implementation, verification; Mayer and Wittrock [13]: represent, plan/monitor, carry out, and self-regulate, and Polya [12]: understand the problem, devise a plan, devise a plan, and look back. No matter problem-solving model is constructed, Chapman asserts that teachers need to have a conceptual and procedural understanding of these problem-solving models to understand the stages required by a problem solver and the thought process involved in finding solutions to the problems being solved.

Fourth, knowledge about posing mathematical problems. This knowledge refers to Silver's [14] opinion which presents problem posing as an activity to formulate a new problem and reformulate the problem given. Furthermore Silver [14] gives the term problem posing applied to three different forms of cognitive mathematical activity, namely: (1) posing before the solution (presolution posing), that is posing can occur before the problem is solved. Problems can be generated from information provided in the form of stories, pictures, diagrams, etc., (2) Posing in solutions (within-solution posing), i.e. posing occur when students solve complex problems. To solve complex problems, students create new, simpler problems that can lead to complex problem solving, and (3) post-solution posing, that is, posings occur when students have solved the problem. Students create new problems that are similar to the problems that have been solved.

The second category of knowledge, namely problem solving pedagogical knowledge, comprises two subcategories. First, knowledge of students as problem solvers. According to Chapman, this knowledge help teachers develop appropriate problem-solving skills for students. generally, this knowledge includes knowledge about problem-solving difficulties experienced by students, characteristics of successful problem solvers, and thought processes in problem-solving. However, to encourage the development of students' problem-solving skills, the current perspective shows that this knowledge can be figured out from a student's perspective by focusing on building what students know and can do in trying to solve problems in their way. Second, knowledge about instructional problem-solving. In particular, Chapman reveals that teachers need to understand learning practices that could
develop students' strategies and metacognitive skills in solving problems. Also, teachers should have strategic competencies to deal with problem-solving challenges during instructional practices.

Furthermore, teachers also need to understand the various effects of the different teaching approaches they select, whether it can be useful or not, and if not, what factors might cause it. Additionally, teachers should be able to decide when and how to provide some interventions, when to give help and what forms of assistance that could promote students' success while ensuring that they maintain their solution strategies. Also, teachers need to know what to do when students are trapped or are using unproductive strategies or time-consuming solution approaches in solving a problem. They are sometimes in a position of not knowing the solution. Therefore, it is necessary to understand how to work well without knowing everything.

The third category of problem-solving knowledge for teaching is the knowledge of affective factors related to problem-solving, such as interest, motivation, beliefs, anxiety, perseverance, and student beliefs. Chapman believes that knowledge of the affective aspects is crucial since it could help teachers to analyse and support students' problem-solving skills based on findings consistent with these factors. Students' beliefs about problem-solving, for example, are important to be understood because this can be an excellent factor for students, and can also be an inhibiting factor when students solve mathematical problems [15]. Therefore, Polya [16] emphasises the importance of teacher attitudes that can help students in problem-solving activities.

4. Teacher teaching practice on mathematical problem-solving

Teacher practice is intended as an implementation or implementation of a strategy, approach, and ideas of learning carried out in the actual class so that there is a direct interaction between the teacher and students in delivering a material. Teacher's practice is influenced by beliefs about the teaching content to be taught, classroom situation, and teacher's pedagogical knowledge. Other influences that are not strongly influenced by social norms of teaching, teacher education programs, teacher's life outside the classroom, and teacher personality traits (Raymond in [17]). Chick [18] argued that the quality of teacher knowledge was determined by two aspects, namely mastery of content about the topic being taught and the learning strategy. In addition, Brahier [19] said that effective teachers not only require a high level of competence in the field of content but also sufficient knowledge about how students learn, and even a set of good teaching activities and strategies and wisdom to know which techniques are best suited to the classroom situation faced. Foong in [20] explained that Singaporean teachers tend to adopt teaching with problem-solving approaches that emphasise content that can be applied to various situations. Thus, many experts express a piece of substantial advice for teachers to teach problem-solving skills by utilising problem-solving tasks as a focus of mathematics learning [21]. For this reason, Sullivan et al. [22] have emphasised to support teachers in developing their classroom activities through challenging assignments. Their findings indicate that in terms of structuring learning structures with problem-solving tasks, teachers need to have clues to questions that can support students to overcome difficulties with learning tasks and instructions that can encourage students who have completed learning tasks to expand their thinking skills.

There are numerous potential approaches for how a teacher should guide their students to complete problem-solving tasks, one of which is consultative teaching. This teaching approach emphasises students to independently and actively build new knowledge and insights using prior knowledge and experiences [23]. In contrast to consultative teaching, directive teaching, teaching where the teacher explains the concept, giving examples of the application of concepts and finally offering students some practice to practice problems [24]. This teaching approach is not recommended as the approach supporting student problem-solving skills. More specific advice about how a teacher carries out consultative teaching practices can be known in more detail during the process of guiding students to complete problem-solving tasks. This guiding process is a complex process where students work within several stages as suggested by Polya [16], namely understanding the problem, devising a plan, carrying out the plan, and looking back. Within the stage of understanding problem, teachers could help students to identify the information required for the need to choose the correct strategies. In the step of devising
a plan, teachers could guide students to find the relationship between a set of information that has been identified and guides them to find the correct strategy. Within the stage of carrying out the plan, teachers could encourage students to use a proper and logical-mathematical procedure while ensuring that they come to a particular set of solutions, whether the answers are correct or incorrect.

Regarding the final stage of problem-solving, that is, teacher teaching practices can be explained from activities that guide students to review the process through checking the answers, checking solutions and the whole thought process, and guide students to generalise new solutions and strategies or even build on previous approaches with new insights. This stage is crucial because these activities are an essential part of problem-solving teaching as it could deepen students' mathematical thinking and improve problem-solving skills [25]. Another important aspect in teaching problem-solving is the teacher should demonstrate the practice of teaching based on the view that problem-solving is a dynamic process where every problem solver should move back and forth from the stages of problem-solving as needed [26].

5. Research on beliefs, knowledge, and teaching practices as interconnected factors: Research reports

We carried out a three-year projects which concern on analysing teacher beliefs, knowledge, and practice of primary and secondary teachers by involving 288 teachers (both primary and secondary mathematics teachers) in four districts in East Java province and 40 teachers who were taking a graduate program of primary education.

The first year project informs the investigation of primary and secondary teachers' belief about the nature of mathematics, mathematics teaching, mathematics learning, and knowledge about mathematical problem-solving. Results of this study indicate those three beliefs were held by the teacher participants as an inconsistent view. They were also reported to have limited knowledge primarily on problem-solving content knowledge such as knowledge of the nature of mathematical problem, problem-solving processes and strategies. This study also found that the teachers' instrumentalist beliefs were consistent with their insufficient knowledge about problem-solving for teaching, while both platonist and problem-solving beliefs were consistent with their sufficient knowledge of problem-solving knowledge for teaching. Another finding was also reported by examining beliefs and teaching practice of one primary teacher about his view about the nature of mathematics, teaching mathematics, and learning mathematics as well as knowledge about content and pedagogical problem-solving. The finding reveals he was identified to have consistent beliefs about nature of mathematics and mathematics teaching and learning. His beliefs were recognised as problem-solving view, in which these are consistent with his sufficient knowledge of problem-solving, there is a gap between such beliefs and knowledge with his teaching practices. The gap appeared primarily on the directive teaching which aligned with instrumentalist view he held in most of Polya’s stages during his teaching practice on six problem-solving tasks. Such a gap was not consistent with beliefs and knowledge he professed during the interview we conducted two months before the teaching observation. This finding supports the view that there might be an inconsistency between teacher beliefs, knowledge, and teaching practice.

The second-year projects also still focus on the three factors, in which teachers who were taking graduate program were selected as participants. Analysis of beliefs in mathematics and learning was examined to 40 graduate students of Primary Education who were taking courses in basic mathematical concepts. The students were asked to fill out a multiple-choice online questionnaire whose instruments were taken from our previous study [5,28-29] regarding beliefs in mathematics, learning mathematics, and teaching mathematics, where the division of the types of philosophical beliefs in each of these categories was based on summaries of Beswick [28]. Analysis of the results of questionnaires is also based on the model proposed by Siswono [5]. Results of such a project show that from 41 participants, there were respectively 19 participants, 5 participants, and 17 participants holding Instrumentalist, Platonist, and problem-solving types in figuring out the nature of mathematics. In viewing how to learn mathematics, there are at most types that are in line with the Platonist, namely the type of active construction of understanding (24 participants), followed by groups with the view of skill
mastery, as many as 14 participants, and at least 3 participants of type the exploration of learner interest. In viewing the way of learning mathematics, most subjects (22 participants) looked to teach to the kind of learner-focused, which is most in line with problem solving, followed by subjects with content-understanding (16 participants), which is in line with the Platonist view, and followed by groups who believe in content performance as many as 3 participants, which is in line with the Instrumentalist type of belief. The results of this table show that there are still many participantss who generally do not have beliefs that are aligned with problem-solving, particularly in the category of beliefs about the meaning of mathematics and learning mathematics.

From these findings, researchers see the need to make it as a reference in developing professional development which emphasise the importance of facilitating students in acquiring knowledge of problem solving for teaching and mathematical knowledge to teach so that they can renew their type of beliefs to become more constructivist which is in line with the concept of solving problems. By providing such kind of professional development, there will be some changes in teachers’ beliefs and attitude toward mathematical problem-solving as illustrated by Guskey [30].

![Figure 1. Model of teacher change](image)

6. Conclusion
The experimental results of the three-year project conducted by the authors simply found that beliefs, knowledge, and teaching practice are discussed as three interdependent factors which determine the quality of a teacher's mathematical problem-solving. Beliefs and knowledge are two factors which simultaneously affect the quality of teaching practice carried out by teachers within their problem-solving instruction. To improve the quality of teachers' mathematical problem solving regarding teacher beliefs, knowledge, and teaching practice, a teacher professional development which support teachers; an understanding on mathematics problem-solving knowledge for teaching and mathematics-related beliefs, as well as experience of conducting consultative teaching is promoted.

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