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Developing teachers' PCK about STEM teaching approach through the implementation of design research

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Abstract. Since the introduction by Shulman in the early 1980s, Pedagogical Content Knowledge (PCK) has been identified as a key teachers' knowledge that influence teachers' classroom activity. The identification of this particular type of knowledge developed awareness that the improvement of teachers' competencies should take the teachers' PCK into account. If the teachers' classroom activities need to be improved, the professional development programs should also aware of the teachers' knowledge and beliefs related to their daily classroom practices. This research was aiming at developing a teacher professional development model with the development of PCK as a main improvement indicator. The research implemented Design Research method. The participants of the research were science teachers and mathematics teachers of Junior High School in Yogyakarta participating in the STEM approach project. The data collected during the processes of preparation, implementation, and evaluation-reflection of the implementation of STEM approach through interviews, focus discussion group, and questionnaires. The research resulted a model of teachers' professional development program that focuses not only on the teachers competencies but also the teachers' knowledge that drive their activities in the classroom. One of the main features of the model is on its time allocation dedicated for teachers to be aware of their value and knowledge system and to reflect on the extent to which their value and knowledge system influence their teaching practices.

Keywords: PCK, STEM approach, Design Research.

1. Introduction

The government and several parties have made efforts to improve teacher competence through various means. The effort is based on the belief that increasing teacher competence is a necessity to improve the quality of learning in schools. This belief is supported by the results of the research of Hattie (2006) which shows that teachers have a contribution of 30% to the success of student learning [1].

However, various efforts have not shown satisfactory results. The PISA test results shows that the learning achievements of Indonesian school students are still low compared to their peers' achievements in various countries [2]. This is an indicator that the quality of learning in Indonesian schools is still low. It also means that the competence of Indonesian teachers in learning needs to be significantly improved. The current teacher professional development need to be improve, there is a needs for new ways in efforts to improve teacher competency.

This paper contains a report about an effort to improve teacher's PCK as a basis for their competence by applying the Design Research method. Design research methods are used to improve teacher competence in applying a new approach to learning, namely the STEM approach. Through the design research method the PCK of teachers to apply the STEM approach to learning was improved.



The activity of increasing teacher competency carried out by researcher was not only the training to improve skills but was also directed at building knowledge and beliefs needed by teachers to apply the STEM approach. The focus on the development of knowledge and beliefs in addition to the development of practical skills to implement STEM is based on the researchers' belief that teacher activity in learning is anchored on knowledge and beliefs about learning pedagogy and the material taught. To facilitate the process of developing knowledge and beliefs, the Pedagogical Content Knowledge (PCK) construct was used.

2. Literature Review

The improvement of teacher competency was directed to develop teachers' capacity to teach using STEM approach. The STEM approach is relatively new in Indonesian education context. The utilization of STEM approach requires several skills that have to be mastered by teachers. The skills can also be used to teach with other approach. Therefore improving teachers' capacity to implement STEM teaching approach was expected to improve teachers teaching skills in a broader term. The mastery of skills and knowledge required to teach STEM teaching approach are a necessity, yet is not sufficient. The teachers will need to have a beliefs that they need to implement STEM approach for the sake of students learning. The teachers have to beliefs that move them to act and to improve their teaching quality.

Since the teacher professional development involve the improvement of the teachers' knowledge and belief, then the concept of Pedagogical Content Knowledge (PCK) was used. The construct of PCK provide a theoretical basis on how teachers' knowledge and beliefs influence their teaching practice. It also provide a sound basis for the rationale of the necessity for the improvement of teachers' knowledge and beliefs if teacher professional development to be significantly successful.

2.1. Pedagogical Content Knowledge (PCK)

Learning is a complex activity. Researchers need tools to understand this complex process. In 1986, Shulman proposed a special knowledge to understand teacher knowledge systems that influence the learning activities. Shulman identified that knowledge as: "... *pedagogical knowledge, which goes beyond knowledge of subject matter per se to the dimensions of the subject matter of knowledge for the teaching ...*" (p. 9) [3]. In 1987, Shulman identified this special knowledge as PCK and defined: "*It represents the blending of content and non-learning into particular topics of understanding, problems are organized, represented, and adapted to diverse interests and abilities of learners, and presented for instruction*" (p.8) [4].

The concept of PCK grows in a system of belief that the teacher's actions in the learning process are representation of his/her system of knowledge. Conversely it can also be said that the teacher's knowledge system determines the learning activities. This perspective is the basis of a study of learning known as *knowledge base for teaching*. The paradigm of knowledge base for teaching develops from the questions: What teachers should know, and are able to do in order to deliver quality teaching [5].

Since Shulman's introduction, the PCK concept has been the topic of studies of researchers from various countries in various fields of learning. Those studies are trying to better understand the nature of PCK including its sources and how it develops. As a result, the concept has evolved. One significant development is the understanding that PCK is not just a knowledge system but also as believed by Magnusson: *PCK is not only formed by a set of teachers' knowledge but also by their beliefs related to that knowledge* [6]. The statement that PCK is not only knowledge but also a belief is in line with the definition of pedagogy which states that: "*Pedagogy comprises teachers' ideas, beliefs, attitudes, knowledge and understanding about curriculum, the teaching and learning process and their students, and which impact on their 'teaching practices', that is, what teachers think, do and say in the classroom*" [7].

Sarkim presented the concept of PCK in Figure 1. [8]

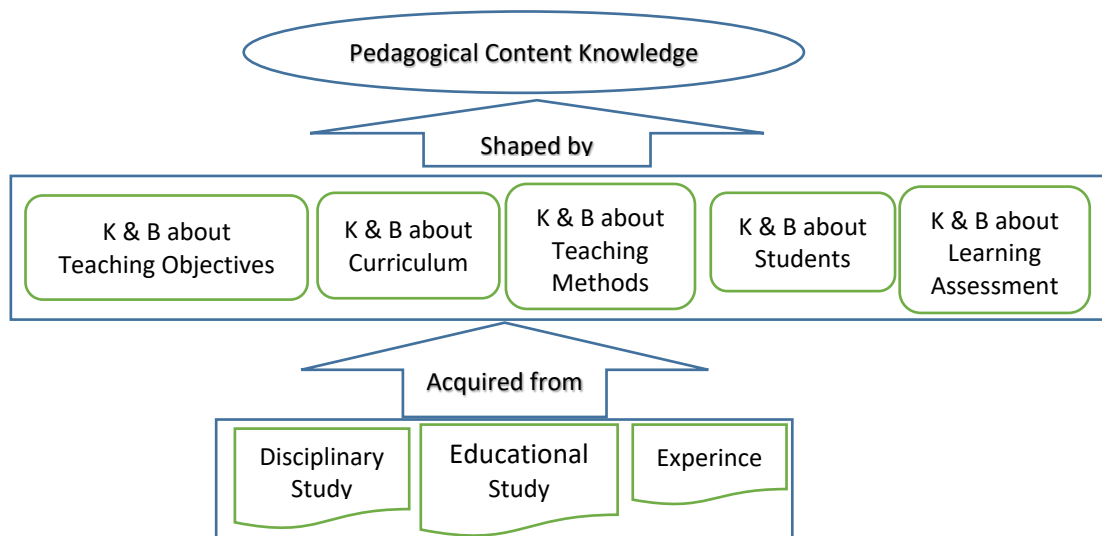


Figure 1. PCK – Components and sources
(K& B: Knowledge and beliefs)

The concept of PCK described above is a reference in the development of teacher competencies in order to be able to apply the STEM approach to learning.

2.2. STEM Approach

The concept of STEM is formulated with different meanings by various researchers. In other words, there is no single understanding of STEM. For example, some researchers interpret STEM as a group of sciences that includes Science, Technology, and Engineering. This concept is often used by policy makers in the government to provide emphasis on the importance of the development of STEM in the present era. Meanwhile there is also a formulation of the meaning of STEM which is more focused on learning, namely the development of skills in the fields of science which are included in the scope of STEM. Despite the fact that there are various variations of the STEM meanings, there are several similarities that arise in the various formulations. Some of these similarities include: covering several branches of science, branches of science are not seen as separate independent knowledge but interrelated.

STEM approach can be defined as the teaching of the disciplines within its umbrella – science, technology, engineering, and mathematics – and also to a cross –disciplinary approach to teaching that increases student interest in STEM relative fields and improves students’ problem solving and critical analysis skills [9].

Teaching and learning by using STEM (Science, Technology, Engineering, and Mathematics) approach has received an important role on increasing a country position in the global economy after this system introduced in 21st century. The teaching and learning in science, technology, engineering and mathematics field have developed become a metadiscipline, an effort to integrate the teaching and learning process in those fields is focused to find inovative solutions for complex problems in this world nowadays. To improve the teacher and learning process in those fields, we have to integrate the application of technology and engineering into science and mathematics teaching and learning process. STEM approach trains the students to solve problems comprehensively from both sides. If we want the teaching and learning process by using STEM approach in schools is success, then we have to improve the competence of the teachers to integrate the application of technology and engineering into science and mathematics teaching and learning process. Therefore, teachers can supervise and teach the students so they acquire very broad knowledge in those four fields [10].

STEM education is a term used to refer collectively to the teaching of the diciplines within its umbrella – science, technology, engineering, and mathematics – and also to a cross –disciplinary

approach to teaching that increases student interest in STEM relative fields and improves students' problem solving and critical analysis skills. STEM as an entity in itself. Integrated STEM education is not just the grafting of technology and engineering layers onto standard science and mathematics curricula. Instead, integrated STEM education is an approach to teaching that is larger than its academic parts [11].

In this research STEM teaching approach was seen as a vehicle to improve science and mathematics teaching in secondary schools to meet new standard of teaching quality. The activity of increasing teacher competencies carried out was directed towards improving the various abilities of teachers related to learning with the STEM approach. In addition, the teacher competency development activities were also directed at developing knowledge and beliefs about the STEM approach. The knowledge that is expected to develop includes: understanding of the nature of the STEM approach, knowledge of learning methods that can be applied to teach with STEM learning. Meanwhile, the ability that is expected to develop through increasing teacher competency activities includes increasing the ability of teachers to make learning plans, implementing learning according to what is planned, evaluating learning, and developing methods and media that are appropriate for learning with the STEM approach. Along with the development of knowledge and capabilities that have been described, the activity of increasing teacher competencies undertaken is directed at building teachers' beliefs about the need to develop learning with the STEM approach.

3. Research Method

The effort to reveal and develop of teacher knowledge related to the lessons learned in teacher professional development activities is in line with Gravemeijer's idea which states that: *if you want to change something, you have to understand it, and if you want to understand something, you have to change it.*" [12]

The improvement of professional teachers carried out applies design research methods. In order to improve teacher competency successfully the activity of increasing teacher competence must be directed to the knowledge and beliefs as stated by Magnusson (1999): *"teacher educators must provide opportunities for teachers to examine, elaborate, and integrate new knowledge and beliefs about teaching and learning science into their existing systems of knowledge and beliefs"*. In other words, Teachers' professional development should be addressed to develop teachers' PCK. [13]

In accordance with the design research method, the teacher's professional development activities include three main steps, namely: 1) preparing for the experiment; 2) experimenting in the classroom; and 3) conducting retrospective analysis.

When translated into concrete actions, the teacher professionalism improvement activities developed by implementing design research were carried out in steps as shown in figure 2. The figure shows that, the first step is to uncover knowledge and initial beliefs about STEM teachers. Based on data on this matter, the activities to increase teachers' PCK about STEM was carried out. In the final stage, the teachers were asked to do reflection and realize their understanding and beliefs about the STEM approach. The figure only shows one process cycle, in reality, the process is repeated for the second and third cycles.

The activity of increasing teacher competency in applying the STEM approach, as shown in Figure 2 includes five main steps. First, disclosure of teachers' knowledge and beliefs about the STEM approach. Second, the teacher and the researcher study the STEM concept and make a lesson plan by applying the STEM approach. The third is implementing learning in accordance with the plans that have been made. Fourth, reflecting and evaluating the lessons learned. At this stage the teacher's knowledge and beliefs about the STEM approach are revealed again. The next stage, namely the fifth stage is to make the learning plan for the next cycle by paying attention to the results of reflection and evaluation on the previous cycle.

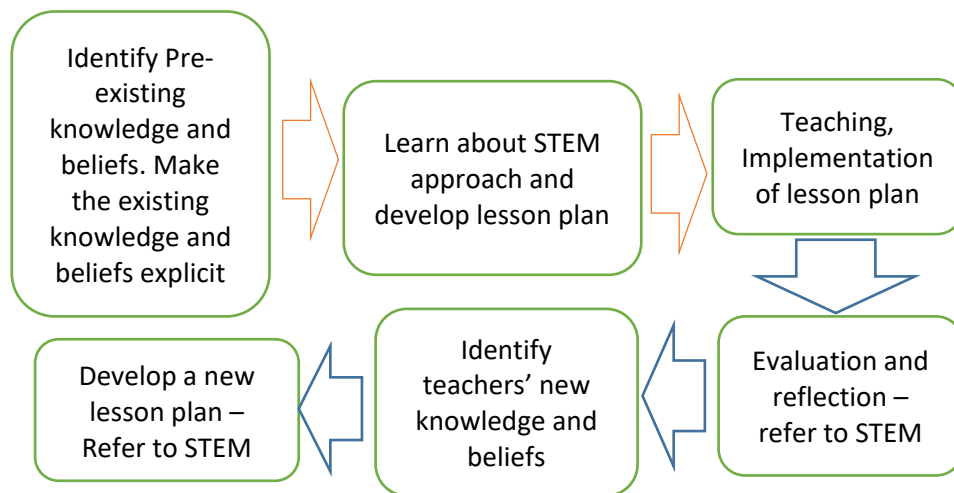


Figure 2. Teacher's Professional Development using Design Research Method

The professional development of teachers carried out applies the 'snowball' principle. In the initial stage, the development of professionalism involved only two teachers from one middle school, one mathematics teacher and one science teacher. Success in the first stage attracted the interest of teachers from other schools until the second year involving 10 teachers from 5 schools. This report was made when phase 2 was completed and the third stage involving 20 teachers was in the preparation stage.

Data was collected through three main ways namely questionnaire, interview, and observation. The questionnaire is used to reveal the teacher's knowledge and beliefs both at the beginning, middle and end of the development activity. Observation is done when the teacher carries out learning.

The data obtained were analyzed quantitatively and also qualitatively. Based on the analysis of the data obtained information about changes in teacher competencies in applying the STEM approach that includes knowledge, beliefs, and skills needed to apply the STEM approach.

4. Results

4.1. Knowledge and belief about STEM approach

At the beginning, a new compilation of two teachers was involved, these two teachers did not yet have knowledge about STEM. Both teachers agreed that they had not been encounter with STEM approach. As expressed by a participant: *"I don't know anything about STEM."*

Despite the fact that they did not understand STEM, the two teachers were willing to try or STEM approach. The agreement of two teachers trying to implement STEM was based on the attitudes 'want to try' and they hope that learning would be more interesting. *"I want to try, may be my learning will be more interesting to my students"*.

The willingness to try, which was shown by two teachers, opened the door for various development reforms. The researcher believes that the basic attitude is important by teachers involved in increasing professionalism. In addition to the

In the second cycle, when the number of participants increased to 10 people, participants who had just joined were asked about their initial knowledge and beliefs about the STEM approach. Most of the new participants have heard the term STEM, but they don't understand the meaning. When asked to write their understanding of the STEM approach, in general they answered that STEM is the integration of learning science and mathematics. As expressed by a participant: *"Learning with the STEM approach is the integration of mathematics and science material"*.

At the beginning of second cycle, the participants was also asked about their opinion regarding whether Mathematics and Science in middle school has to be taught as separate subject all the time. The answer indicate that the participants divided into two opposite opinion with almost similar portion as shown in Figure 3.

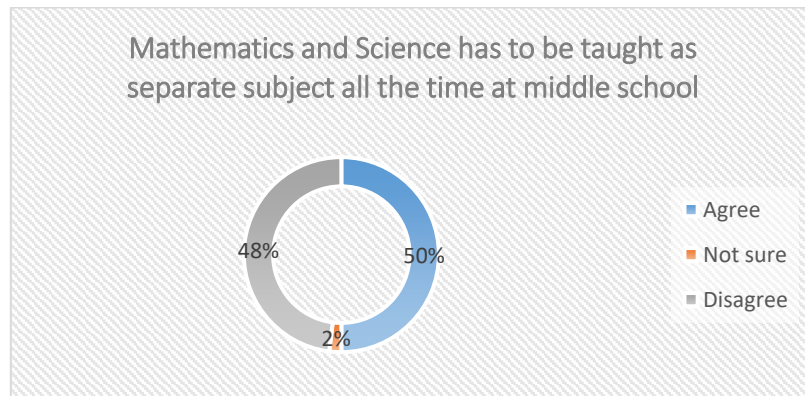


Figure 3. Initial Teachers' opinion regarding the teaching of Mathematics and Science at middle school

Despite the fact that about 50% of the participants beliefs that Science and Mathematics have to be taught as separate subjects, all of them wanted to try to learn and implement STEM approach in their teaching as shown in Figure 4.

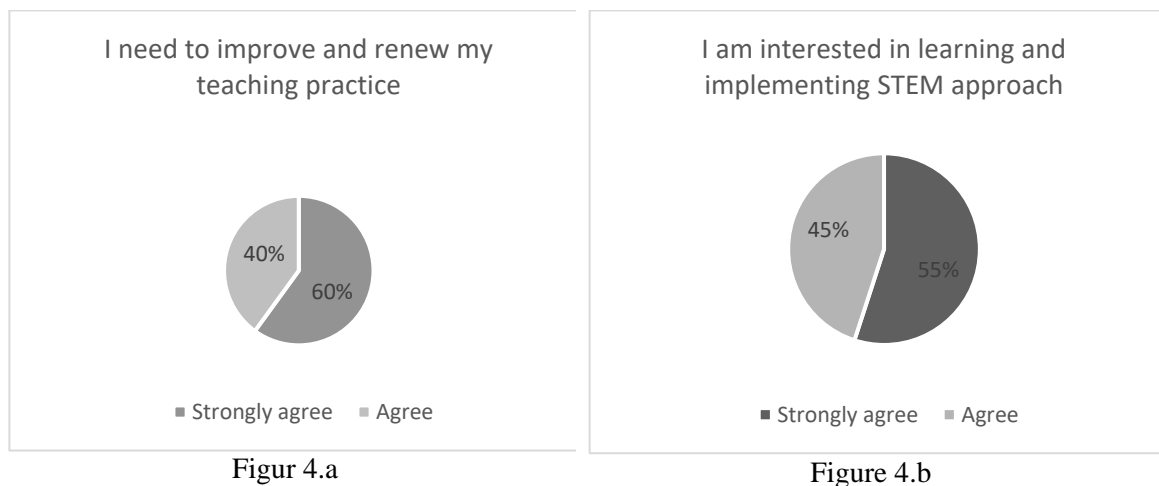


Figure 4. Participant's beliefs about the need to improve and renew their teaching (a); and participants interest to learn and implement STEM approach.

The eagerness of the teachers can be seen from the following expression:

- Teacher 1: *"I want to try this out. I think it would help my students to develop 4Cs"*.
- Teacher 2: *"I want to try it, the approach may help the students to understand a difficult concept about variable"*.
- Teacher 3: *"I think this approach more interesting to my students, I will try it"*.

By the end of the cycle the teachers participated in this program have gained new understanding about STEM teaching approach and also have developed their beliefs about STEM approach. Following are several teacher's expression about STEM approach.

Teacher 2: *"Broadly speaking there are two opinions about STEM: Departing from appropriate technology, the project then studied the material, another view: combining some subject matter then looking for a project"*

Teacher 3: “*STEM approach integrates math, science, and technology ... it makes students develop comprehensive understanding and develop students’ thinking skills... Is it possible to combine with other subjects?*”

Teacher 4: “*STEM approach is a new way to see the teaching ... to meet the challenge of current society needs... I want to continue this project since it help develop students’ creative and critical thinking*”.

Teacher 5: “*Learning that is interesting for children is also interesting for me because a new thing between science and mathematics is put together, so like a kind of thematic learning, only science and mathematics are integrated.*”

Teacher 1: “*I think I have changed in my teaching paradigm – I have a freedom to manage learning*”.

The teachers expression demonstrated that the knowledge and belief about STEM teaching approach held by the teachers participating in the teacher professional development has changed significantly both inn term of knowledge and their beliefs. By the time of this report ready, the cycle three of the project has been started with 24 teachers participating, including 10 teachers who have participated in the second cycle.

4.2. Teachers skills to implement STEM approach

In addition to the improved knowledge and beliefs about STEM approach, the teacher participating in this project also developed their skills-related to teaching. Several skills they developed during the project including:

- a) Analyse teaching content and learning objectives to identify the topics and learning objectives that can be integrated into a particular theme and activity.
- b) Develop lesson plan and worksheet to facilitate learning process of the students to maximise the students learning potentials.

5. Conclusion

- a. Design Research can be implemented in teacher professional development programs. The utilisation of research design to the teacher professional development enabled program administrator to revise and improve the effectiveness of the program.
- b. Pedagogical Content Knowledge (PCK) has provided theoretical basis for the improvement of teachers’ competencies. PCK provided a theoretical framework to understand how teachers’ knowledge and beliefs influence their teaching practice.
- c. Teaching quality can be improved when teacher’s competencies were upgraded and their beliefs regarding new approaches of teaching drove their willingness to implement new approach.

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