TPACK development of prospective physics teachers to ease the achievement of learning objectives: A case study at the State University of Malang, Indonesia

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Abstract. In today’s Industry 4.0 era, the development of science and digital technology is progressing so fast. In the context of education, multimedia technology plays a crucial role. The use of internet and digital technology in the teaching and learning activities is incredibly helpful for accelerate and facilitate student learning, so that the learning objectives can be more easily accomplished. The implementation of ICT-assisted instruction in physics will be meaningless if it is not integrated with the subject-matter knowledge of physics and instructional strategies used. This study aimed to reveal the efforts made by prospective physics teacher candidates in helping students gain better understanding of the course material using the TPACK framework. The type of research was qualitative with a case study approach conducted in the Physics Education program at the State University of Malang in Indonesia. The results showed that the efforts of physics teacher candidates in using ICT in the TPACK framework to achieve the learning objectives have been quite varied, but further development work and testing involving students are still required.

1. Introduction

Information and communication technology (ICT) at the world level has been developing very rapidly in industrial revolution 4.0. As a result, all industry sectors seek to apply and integrate the ICT. The development of ICT has also changed people in various aspects of life. Despite its many benefits, the development of ICT (especially internet and digital technology) presents many challenges for education. Teachers, for instance, have to experience a paradigm shift in teaching and learning. In the instructional process, ICT does not only serve as a tool to aid instruction, but also function as a source of learning. The integration of ICT knowledge, pedagogical knowledge and content knowledge in one lesson is designed to accelerate the achievement of learning objectives.

Integrating technology into instructional activities to create meaningful learning is not easy since teachers should relate to the characteristics of the material to be taught and the basic knowledge of teaching [1-4]. It has been acknowledged that pedagogical content knowledge (PCK) is the knowledge base a teacher must have to teach. PCK is an integration of subject content knowledge and pedagogical knowledge, which is a unique way to teach physics so that it is easy to facilitate student understanding [5-6]. PCK was initiated by Shulman [1]. Research has shown that PCK have the
greatest influence on instructional practices compared to subject content knowledge and pedagogical knowledge [2, 7-8]. Several educational institutions include PCK in their education reform documents with reference to the importance of PCK for teachers, such as the following institutions in the United States: American Association for the Advancement of Science [9], National Research Council [10], National Council of Teachers of Mathematics [11] and National Board for Professional Teaching Standards [12]. Researchers and policymakers believe that PCK can not only confirm its importance, but also contribute to the effectiveness of instruction.

Teacher knowledge for technology is developed into technological pedagogical content knowledge (TPCK). TPCK is an integration of technology knowledge, subject content knowledge and pedagogical knowledge developed by Mishra and Koehler [13]. To simplify the pronunciation, the acronym was renamed by adding letter “A” so that it becomes TPACK [14]. TPACK is a framework built on the concept of PCK developed by Shulman, interacting with technological knowledge, to deliver effective instruction [13]. TPACK requires the existence of a unique multi-interaction and synergy between content, pedagogy and technology [15]. The integration of technological knowledge (TK), content knowledge (CK) and pedagogical knowledge (PK) produces four combinations, namely pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), technological content knowledge (TCK) and technological pedagogical and content knowledge (TPACK). In total, there are seven components of knowledge teachers or prospective teachers in physics must have in planning technology-based instruction.

Information and communication technology (ICT) is a medium that includes information technology and communication technology. In its development, the media appear in various types and formats. The types of media that are widely developed are computer media, network technology and the internet. A computer is a tool that can be utilized as the main medium to support instructional activities because it has various capabilities. Its capabilities include fast virtual response to user input, storage and manipulation capacity and ability to control and manage various instructional media and materials such as movies, videos, slides and printable information. Even further, there has been developed multimedia technology that merges data, voice, video, audio, animation, graphics, text and sound. Internet-based instruction allows synchronous learning or asynchronous learning.

TK refers to knowledge of technology, tools, methods, and learning resources related to the field of science. According to Koehler and Mishra [15], "TK is knowledge about certain ways of thinking about, and working with technology, tools, and resources... including information and communication technology". A previous study found that physics teacher candidates have sufficient technological knowledge and skills and are even quite adept at operating the computer and word processing software [16]. The level of ICT skills of the 2016/2017 prospective physics teachers taking the Development of Physics Learning Program (DPLP) course was not far different from the 2015/2016 class. The knowledge of ICT as described above relates to programming competency mastered by a small number of physics teacher candidates.

Another form of knowledge is CK or the knowledge of subject matter to be taught, which in this case is physics. This content knowledge includes knowledge of concepts, theories, ideas, frameworks, scientific methods and their application in everyday life. In this component of knowledge, teachers are required to understand and master the material being taught and its characteristics [13]. The subject-matter knowledge of many physics teacher candidates is weak, especially in determining important concepts of physics to be taught, It can be seen when as suggested by their performance when teaching the tenth or eleventh grade students a topic in a 3-hour lesson. The scope and objectives of learning to be achieved are in accordance with the requirements of core competencies and basic competencies listed in the Syllabus of Senior High School in 2016. Apparently, only 60% of teacher candidates answered the basic concept questions given by lecturers correctly. Therefore, the DPLP course needs to involve more activities to strengthen the understanding of the subject areas of physics, especially those to be designed for lessons. The selected activities should be able to illustrate the basic concepts to be taught as outlined in the concept maps.
Furthermore, PK or pedagogical knowledge includes knowledge of curriculum, lesson plan, student worksheet, instructional scenario, instructional practice, classroom management, instructional objectives, student motivation techniques, and assessment tailored to the level of student development [17, 18]. PK includes the understanding of the cognitive, affective and social aspects of instructional theories and how they can be applied. In other words, PK is the science of learners, the process of teaching and learning and assessment [15].

Pedagogical content knowledge (PCK), as the most fundamental knowledge a potential teacher should have, is an integration between content knowledge and general pedagogical knowledge [2-4, 19]. PCK is a form of unique or specific amalgam of knowledge possessed by prospective teachers to teach certain materials comprehensively to students in such a way that students can understand easily [2, 3, 20]. Shulman also explained that PCK can be categorized into two major groups, namely (1) knowledge of representation: analogies, illustrations, examples of daily life applications, demonstrations, visualizations and explanations that make concepts are easier to understand, (2) knowledge of difficulties in understanding teaching materials and the interconnectedness of concepts [19, 21].

The next knowledge component is technological pedagogical knowledge (TPK), which is an understanding of how instructional practices can change with the use of technology that supports teaching and learning activities and facilitates the delivery of the material. ICT is, in fact, highly flexible—it can serve as a source of learning and as a medium for delivering lessons e.g. the use of animation in teaching abstract and invisible stuff. ICT helps teachers to develop their creativity and innovative thinking; it does not mean that teachers have to be programmers.

According to Mishra and Koehler [13], TCK is defined as "... the knowledge about the manner in which technology and content are reciprocally related". It is the knowledge of the way in which technology and related content are reciprocated. Prospective teachers need to understand not only the subject matter they teach but also the way in which the subject matter can be delivered with the application of technology. The reciprocal nature of TCK can be seen most clearly in physics, where technological advances literally transform and broaden the understanding of scientists about nature [22]. TCK may also be understood as the knowledge needed to identify and select technological tools and resources in a particular subject area within the material.

Furthermore, research by Purwaningsih and Yuliati [16] indicated that physics teacher candidates have enough knowledge and skills and are even quite adept in operating word processing program. However, they still lack the mastery of physics content knowledge [23]. The results of the research suggested that it is necessary to improve the content knowledge mastery of these teacher candidates by describing the lesson content using a concept map. Before applying technology in to deliver the material, the prospective physics teachers are reinforced by creating concept maps for each material to be taught.

To improve students' motivation, physics teachers are required to visualize abstract material, demonstrate phenomena that are unlikely to be presented in the classroom, and assist in the investigation process [24]. Thus, the integration of technology in learning is expected to help students understand physics problems more quickly. This is in line with the Ministry of Education of Indonesia through the 2013 Curriculum which requires teachers to always integrate technology in teaching and learning activities [25]. To that end, prospective physics teachers must master the material taught so that they can choose the technology appropriately [26] and analyze the characteristics of the material [27]. Prospective physics teachers should also consider teaching strategies that are appropriate to the technology used. This kind of consideration indicates an understanding of pedagogical knowledge [28]. Furthermore, this research was conducted to understand and apply the TPACK concept in the Physics Education program, State University of Malang in order to facilitate prospective physics teachers to deliver lessons more effectively.
2. Research Methods
This study used a qualitative design with the case study approach conducted in the Physics Education program, State University of Malang, Indonesia. The subjects of this research were one lecturer teaching TPACK and one DPLD class consisting of 18 physics teacher candidates who apply TPACK in teaching. Research data were collected by examining lesson plans made by the teacher candidates, peer teaching observation and in-depth interviews. Furthermore, the collected data were analyzed through several stages, i.e. data grouping, data categorization, data reduction, and conclusion drawing.

3. Results and Discussion
Discussion of the results of this study is reviewed from two sides, namely the DPLP lecturer and prospective physics teachers. The review on the DPLP lecturer teaching the planning of TPACK includes the efforts made by the lecturer in the teaching and learning process. The review on the physics teacher candidates as students learning about lesson planning includes the efforts made by the physics teacher candidates in applying TPACK in lesson planning and delivery.

3.1. Deepening the TPACK understanding of physics teacher candidates at the State University of Malang
TPACK materials were taught by physics education lecturers in the DPLP course. This course was given to physics teacher candidates in semester 7. One of the competencies expected to be gained by physics teacher candidates after completing this course is the ability to make lesson plans and deliver lessons to senior high school students. Therefore, in this course, prospective physics teachers were trained to plan lessons and implement them in peer teaching. Then each prospective physics teacher tried to execute the lesson plan in a small group through peer teaching (microteaching). Alternately, they took turns becoming the teacher and students in the classroom.

The instructional model used in the PDPL course was a modification of the project-based learning. The syntax of the model of modified project-based learning consists of six phases as follows.

- Focus on the problem. In this phase, the lecturer presented problems to be discussed by the physics teacher candidates. The problems were related to student condition, existing facilities in the school and, specifically, difficulties experienced by students in studying certain materials. These physics teachers candidates were asked to plan their lessons and determine the basic competencies to be achieved. Then, they should elaborate the competencies into indicators of competency achievement.
- Describe the physics content using concept mapping and CoRe. In this phase, there were two main activities that must be done by prospective physics teachers to prepare a concept and CoRe map. The goal was to bring about an understanding of the content of physics and the selection of topics to be covered.
- Design a lesson plan based on the problem. In this phase, the main activity was to prepare learning repertoire of instructional tools consisting of the lesson plan and student worksheet equipped with learning media that will be used. The preparation of the instructional tools in this phase was based on the concept maps and CoRe prepared in phase 2.
- Peer assessment and progress of the project. In this phase, the physics teacher candidates conducted self and peer assessment on the instructional tools prepared before.
- Implementation of the lesson plan. In this phase, physics teacher candidates applied the instructional tools in microteaching activities. One became the model teacher, while the rest acted as learners while observing the instructional process.
- Reflection and evaluation. In this phase, physics teacher candidates and teachers reflected and evaluated the observation results during peer teaching.

The preparation of the learning tools was done in accordance with the sequence of instructional steps above, from a group work guided by the lecturer to working independently with the freely chosen topic of the material. Discussions and consultations were conducted online. In this study, the
review was focused on the ICTs used by physics teacher candidates in planning and implementing lessons. The instructional process followed these six steps.

3.2. The implementation of the TPACK concept by physics teacher candidates

The interview and observation results showed that the lesson activities planned by the physics teacher candidates were grouped into preliminary activities, core activities, closing activities and assessments. The main goal of the preliminary or apperception activities is to prepare students to concentrate on the problems that will be discussed. In addition, these activities can motivate and attract students' attention. Most of the physics teacher candidates presented videos about related topics under discussion e.g. video displaying a submarine to teach the law of Archimedes (dynamic fluid), video showing a child playing trampoline or swinging when explaining vibration and video about archery for discussing elasticity. Some performed demonstrations using plasticine and marbles where students were asked to make containers from plasticine so that they could hold many marbles without sinking. Furthermore, a reward was given for groups that could make a container that could hold the most marbles. There were also prospective physics teachers performing demonstrations, such as demonstrating the influence of wing positions on aircraft movements using self-made airplane props. Another prospective physics teacher made a series-parallel circuit with several switches to let the students guess how the light bulbs in the circuit work. These results showed that all of the physics teacher candidates had tried to utilize ICT in starting the lesson. Some physics teacher candidates who did not use ICT in their lesson have their own reasons. Those using plasticine, for instance, argued that students could actually enhance their creativity by creating various forms and at a low cost.

For the core activities, there were several variations made, namely: making animations and simulations to visualize events that take place too quickly for the human eyes to see. For example, showing the motion of a rope on a vibration, an airplane that is landing or taking off, an object undergoing uniform linear motion (e.g. an elevator) and that undergoing uniformly accelerated motion, free fall motion and parabolic motion. Some physics teacher candidates used the PHET program to conduct experiments on vibrations, waves, electron flows, electrical circuits and others.

The physics teacher candidates also prepared teaching materials in the form of e-books (electronic books) and used Edmodo and Moodle to communicate tasks or have discussions. Some even developed programs so that the teaching materials can be accessed on Android phones. Although the results have not been optimal, the understanding of TPACK can encourage physics teacher candidates to become creative using the help of technology to facilitate and accelerate the achievement of goals. It is hoped that the use of the TPACK concept in the development of instructional activities can contribute to improving student learning outcomes. Nevertheless, it does not mean that the absence of technology in the instructional process prevents the achievement of goals.

4. Conclusions

The TPACK understanding of physics teacher candidates in the Study Program of Physics Education, State University of Malang, Indonesia was developed during the course of Development of Physics Learning Program. The final goal of this course is to train physics teacher candidates to plan and deliver lessons using ICT. The instructional process is carried out through six steps resulted from a modification of the Project-Based Learning model, namely focusing on the problem, describe the physics content using concept mapping and CoRe, designing a lesson plan based on the problem, conducting peer assessment on the progress of the project, implementation of the lesson plan, reflection and evaluation. The focus of the research is on the efforts made by prospective physics teachers to achieve the goals set out in the planning and implementation of instruction. Results showed that some physics teacher candidates did not want to use ICT in their instruction. Although not yet optimal, the efforts made by those who wanted to use technology in teaching are well worth, and the results are quite varied. Overall, follow-up development work is indeed required to expand physics teacher candidates’ knowledge of useful ICT-related programs for teaching.
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