

# Improving the problem-solving skills through the development of teaching materials with STEM-PjBL (science, technology, engineering, and mathematics-project based learning) model integrated with TPACK (technological pedagogical content knowledge)

Endang Purwaningsih<sup>1\*</sup>, Annisa Maya Sari<sup>1</sup>, Lia Yuliati<sup>1</sup>, Kadim Masjkur<sup>1</sup>,  
Bahrul Rizky Kurniawan<sup>1</sup>, and Megat Aman Zahiri<sup>2</sup>

<sup>1</sup>Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Jl. Semarang 5, Malang, 65145, Indonesia

<sup>2</sup>Departement of Educational Sciences, Mathematics, and Creative Multimedia, Faculty of Education, Universiti Teknologi Malaysia, Sultan Ibrahim Chancellery Building, Jalan Iman, 81310 Skudai, Johor, Malaysia

\*endang.purwaningsih.fmipa@um.ac.id

**Abstract.** The biggest challenge for teachers in this industrial revolution 4.0 is to create a learning design that improves students' problem-solving skills. Many students face difficulties in applying physics concepts in life since their problem-solving skills are relatively low. Therefore, valid, practical, and effective teaching materials with the STEM-PjBL model integrated with TPACK can be used as the breakthrough. This learning tool is packaged in five steps with various learning experiences, and the students are directly involved in using ICT, making a video, PPT, and using moodle. This research and development used 4D design with four stages, i.e., 1) define, 2) design, 3) develop, and 4) disseminate. In the define and design stages, need analysis and development of draft teaching materials were carried out. Development is an expert validation stage, and its results were declared as very valid. Dissemination is a limited trial phase with one group pretest-posttest design to see its practicality and effectiveness. The results of dissemination were stated to be very practical, showing that the learning plan can be well implemented. The students' problem-solving skills increased after they attended learning by using the developed device. Other findings showed that students were more excited, happy, and comfortable in learning physics.

## 1. Introduction

Many students have difficulties in learning physics [1], especially in solving problems. These difficulties occur because students have disorganized physics conceptual understanding and they do not know the relationship between one concept to the other concepts and their application in everyday life [2]. Problem-solving skills cannot be separated from conceptual understanding skills. Therefore, problem-solving skills in learning physics are needed [3]. The importance of problem-solving skills for students is strengthened by the mission and orientation of the 2013 Curriculum so that students have the skill to solve problems in real life. The problem-solving skills are needed to solve physical problems and bring forth creative and innovative solutions in the 21<sup>st</sup> century (Partnership for 21<sup>st</sup> Century Skills, 2017). When students learn the Conservation Law of Momentum, they know the



concept of Newton's 3rd Laws, but they cannot relate it to the problem of the Conservation Law of Momentum [4]. Many students still have difficulties in solving problems related to Momentum and Impulses due to their less understanding of the basic concepts. They are hard to associate one concept with another concept [5]. Learning physics involves the integration of conceptual knowledge with problem-solving [2]. Hence, a learning model that could train students in applying theories to solve a problem is needed [6]. Likewise, students' skills to utilize technology and information is required to solve complex problems. Based on the explanation above, problem-solving skills are very crucial for students, but unfortunately, students' problem-solving skills are still low. One of the reasons is the traditional teaching and learning process delivered by teachers only transfer knowledge so that the learning is less effective. Learning experiences provided to students are less varied and students' learning activities are lacking. Therefore, students' conceptual understanding and problem-solving skills are low. In this work, to improve the problem solving skills of the Momentum and Impulse, teaching materials were packaged with the STEM-PjBL integrated with TPACK, which is valid, practical, and effective.

The 2013 curriculum has provided a reference in selecting learning models that are in accordance with scientific approaches and can improve problem-solving abilities. The problem-solving abilities include PjBL and PBL or Discovery Learning, in which the learning model must be adjusted to the content characteristics [7]. PjBL can encourage students to construct their knowledge through a process of observation, experimentation, and experience in doing projects that are compatible with constructivism theory [8]. Other impacts of PjBL implementation are students can enjoy learning, build confidence, link concepts to solve the problems, and build teamwork. The difference between PjBL and other learning models are, in PjBL, students will do project design and make activities, so they practice and create activities [9]. PjBL is a learning model that fits the material characteristics of Momentum and Impulse. Basic Competence in the 2013 Curriculum states that students are expected to be capable of presenting the results of testing the application of the Conservation Law of Momentum, for example, on a water rocket. Therefore, in the learning device developed, students are allowed the opportunity to design and do a simple project in the form of a water rocket and test the water rocket. However, the PjBL model, in its syntax, does not explicitly link with the use of technology. Belagra & Draoui explained that the integration of technology in the PJBL is a strategy that can practice problem-solving skills [10]. In learning science, the links between science, technology, and other sciences are inseparable[11]. The connection among science, technology, engineering, and mathematics in learning can be realized in STEM learning.

The enforcement of STEM in education in the period of the industrial revolution 4.0 is rife [12]. Students in various countries view that STEM learning can guarantee their future careers [13]. STEM is the right learning to be developed in designing learning to improve the quality of problem-solving skills in the 21<sup>st</sup> century [14]. Morrison explained that STEM learning makes students have better problem-solving skills and enhance technology utilization skills [11]. The STEM learning experience is similar to the principles that underlie PjBL. Therefore, PjBL integrated with STEM (STEM-PjBL) can improve students' problem-solving skills [15]. Each of STEM and PjBL has advantages and disadvantages so that this merger is complementary. At PjBL, students gain experience of making products to understand concepts, while in STEM learning, students have experience of designing and redesigning. Thus, STEM-PjBL can motivate and encourage students to think analytically, improve communication between friends, and enhance problem-solving skills [16]. STEM-PjBL has been developed to improve students' problem-solving skills and information technology communication skills [17]. Laboy-Rush (2011) developed STEM-PjBL consisting of five phase, that are reflection, research, discovery, application, and communication [18]. However, based on syntax, the way to regulate the use of technology in learning to be meaningful does not appear explicitly. The integration of technology in learning cannot be done haphazardly but its relation to the characteristics of material content and pedagogy must be considered [19]. The integration of technological knowledge, material content knowledge, and pedagogical knowledge has been developed into a framework called TPACK [20].

Initially, Shulman (1986) formulated that a professional teacher should have a PCK (Pedagogical Content Knowledge), which is an integration of content knowledge (CK) and pedagogical knowledge

(PK). PCK is teacher's capability of how to determine the topic of material content, teach a particular material content with multiple representations, and illustrate the material so that students easily understand the material. Finally, [21] integrates technological knowledge (TK) in PCK so that it becomes TPCK or TPACK. Thus, there are three key components of knowledge namely TK, CK and PK. Those three elements interact with each other to produce four components, namely TCK, PCK, TPCK also TPACK. Through the TPACK components, the utilization of technology in learning is in accordance with its functions and needs. For example, TCK uses technology to explain abstract material, and TPCK uses technology to help learning strategies.

Based on the explanation above, this study aimed to develop physics teaching materials with a STEM-PjBL integrated TPACK model on Momentum and Impulse material to improve students' problem-solving skills. The developed teaching materials consist of Teacher's Book and Student's Book. The teacher's book contains 1) Syllabus of Momentum and Impulse with core competency and basic competency 3.10 and 4.10, 2) Lesson plan designed for four meetings each of which contains particular indicators, learning objectives, classifying learning material into facts, concepts, principles and procedures, determining learning strategies at each face-to-face, compiling material uploaded in moodle, determining the chosen media adapted to the TPACK component, learning activities tailored to the STEM-PjBL syntax, 3) Instructions for assignment of water rocket projects, instruments and rubric assessment of water rocket projects made by students, and procedures for conducting experiments, 4) instrument of problem-solving skills assessment consisting of questions and answers and rubric assessment (questions for pre-test and post-test).

The Student Book contains a brief description of the material being studied, examples of water rocket design, instructions for making water rockets, tasks including 1) project assignments to make water rockets, 2) videos of making water rockets, 3) making presentations in the form of power points to explain materials and procedures for doing projects, 4) student worksheets to test the results of project assignments accompanied by mathematical analysis.

## 2. Research Methods

Research and development of teaching materials in this study used 4D design through phase, namely 1) define, 2) design, 3) develop, and 4) disseminate. The define stage consisted of designing objectives, determining learning material and assessment instruments based on the analysis outcomes. In detail, the define stage consisted of five activities. The first was front-end analysis by studying the fundamental problems improved in this study, which were problem solving skills. The students were not accustomed to linking knowledge of a concept with other concepts and the use of ICT. The second activity was learner analysis by studying the students' characteristics, through has a discussion with teachers and students as well as questionnaires used to identify students' abilities to the material, students' experience working on project assignments, and the use of ICTs and facilities related to ICT. Based on the data obtained, the learning was designed, the appropriate model, strategy, and media were determined, as well as the technology was used. The third activity was task analysis by identifying the main abilities expected to be obtained by students and analyzing the basic competence (KD) requirements referred to KD 3.10 and KD 4.10. This task analysis was to ascertain whether the skills expected to be achieved by students were included in the assignments designed in the Student's book. The model was designed in the form of STEM-PjBL integrated with TPACK, with the project assignment of making a simple water rocket to meet the KD's demands. The fourth activity was concept analysis by identifying the main concepts to be taught and arranging the order of the concept in a hierarchy to achieve the expected goals. The last activity was specifying instructional objectives carried out by compiling tests based on the goals or indicators expected to be attained and determining the assessment format and rubric.

At the design stage, the development of the design was carried out in some activities. The first activities were constructing criterion-referenced tests, designing learning activities based on objectives served as benchmarks, designing tests used, developing the guidelines of the project making and instrument of problem-solving skills, and completing water rocket project assignments. The second activities were determining communication media with students outside of face-to-face hours i.e., with moodle, and assigning students to video their activities while working on the project. The third activity

was format selection by designing the contents of the Teacher's Book and Student's Book. The Teacher's book contains syllabus, lesson plans compiled based on the STEM-PjBL syntax, the essay of Conservation Law of Momentum to test problem-solving skills, answer keys, assessment rubric, answer keys for Student Worksheets, guidelines for making water rockets. The Student Book contains a summary of the material, a guide to making water rockets, a Student Worksheet to testing water rockets, exercises to solve problems through five stages namely focusing on problems, analyzing problems using physics concepts, planning solutions, carrying out plans, and evaluating results. The last activity was initial design by consulting the teaching materials to some experts to get input and revision.

The development stage consisted of some activities. The first activity was to obtain validity data of Student's Book and Teacher's Book. This activity was an expert appraisal in which the teaching materials were validated by three experts, namely a lecturer of the Department of Physics and two teachers of MAN 1 Malang. Validity analysis was performed on the data from the product validation by experts. The validity test obtained quantitative and qualitative data. After being revised, the students of MAN 1 Kota Batu conducted a test to obtain the Student's Book readability data. The result of the validity and readability tests were used to improve the Teacher's Book and Student's Book. Meanwhile, the developmental testing was carried out in a limited trial by implementing the Teacher's Book and Student's Book in one class consisting of 33 students. At the time of implementation, practicality and effectiveness tests were carried out. The practicality of the Teacher's Book and Student's Book was measured based on observational data on the validity and students' responses to learning. The effectiveness of the Teacher's Book and Student's Book was obtained from the results of the analysis of the different pre-test and post-test data of MAN 1 Malang students' problem-solving skills. The constraints occurring during the implementation were used as a basis for revisions to the Teacher's Book and Student's Book.

At the dissemination stage, validating testing was carried out by conducting a summative evaluation of the Teacher's Book and Student's Book. The validity, practicality, and effectiveness of both books had been tested in a limited trial in one class. The implementation of learning using the Teacher's Book and Student's Book need to be tested in several classes to see the consistency of the results, this has not been implemented.

### 3. Results and Discussion

The validity of the Teacher's Book and the Student's Book was determined based on the content and construct validity. The assessment of the validity of teaching materials included lesson plans, student learning materials, student worksheets, learning observation sheets, and student response sheets. The criteria for the average score of validity, namely  $3.3 < \text{Very valid} \leq 4.0$ ;  $2.3 < \text{Valid} \leq 3.3$ ;  $1.75 < \text{Invalid} \leq 2.5$ ;  $1.0 \leq \text{Invalid} \leq 1.8$ . The results are shown in Table 1.

**Table 1.** Validity Test Results

Components	Content Validity		Construct Validity	
	Score	Validity	Score	Validity
Lesson Plan	3.61	Very Valid	3.52	Very Valid
Student Learning Materials	3.42	Very Valid	3.42	Very Valid
Student Worksheets	3.32	Valid	3.43	Very Valid
Learning Observation Sheet	3.52	Very Valid	3.61	Very Valid
Student Response Sheet	3.62	Very Valid	3.62	Very Valid

Based on Table 1, the results show that the developed teaching materials are categorized very valid for use in limited trials. Practicality was tested based on the consequences of observations of the implementation and suitability of learning for learning plans developed. The observation was carried out by two observers, by putting a checkmark (√) on the observation sheet and adding notes if there were essential activities unrecorded on the instrument. The average scores of the two observers are shown in Table 2. The criteria used to determine practicality were the same as the criteria for

validation. The results of this observation indicated that the developed teaching materials could be implemented in the school.

**Table 2.** Practicality and Reliability Tests

Implementation Aspects	Practicality and Reliability	
	Score	Practicality
1. Reflection	3.52	Very practical
2. Research	3.52	Very practical
3. Discovery	3.63	Very practical
4. Application	3.51	Very practical
5. Communication	3.42	Very practical

Based on Table 2, the results indicate that the developed teaching materials are practical for use in learning. The effectiveness of the teaching materials was measured by likening the students' pre-test results with the post-test results using the one-group pretest-posttest design. This design used t-test, where the significance of alpha was 0.05. Then, the pretest-posttest results data were tested using N-Gain to see the improvement of the students' problem-solving skills after using the developed teaching materials in learning. There was a transformation amid the pre-test and post-test the results with t-count ( $0.0001 < t$  table (0.05)). In addition, the developed teaching materials could improve the students' problem-solving skills with N-Gain by 0.56. Thus, the developed teaching materials are effective in improving students' problem-solving skills in learning Physics.

At the limited trial, the students created a water rocket race. Eight groups joined the competition T with criteria based on the distance of the launch of the water rocket, the video of making water rocket, and the results of analyzing on the worksheet. Each group made a water rocket using the same and predetermined tools and materials. However, the location of the water rocket wings was untold to the students.

The assessment of problem-solving skills relied on five indicators, namely 1) focusing on the problem, 2) analyzing the problem using Physics concepts, 3) planning a solution, 4) executing the plan, and 5) evaluating the results. Based on the analysis of the answers to the results of the pre-test and post-test with five indicators of problem-solving skills, most students had difficulty when they analyzed problems using the concept of physics. Meanwhile, most students could meet the evaluation of the results indicators well. However, there were some obstacles in communication using ICT at the limited trial. The students faced difficulties when uploading videos made into moodle. The students had no obstacle during the process of making a water rocket video. The solution was taken to overcome the problems in uploading videos. Finally, the videos were collected through the flash disk on face-to-face. In addition, the use of moodle was not optimal as a means of communication outside of head-on hours because the students were not used to it. The students preferred to use Whats App as a way of communication outside of head-on hours.

Students' responses to learning using the developed teaching materials were different from their responses to learning usually carried out at school. Students' activities related to this material included discussions on solving problems, designing water rockets, making water rockets, making videos of making water rockets, conducting experiments with water rockets made, holding inter-group competitions to test the range of water rockets that have been made, and discussing the linkages of the results of water rockets with the material of Momentum and Impulse. Besides, this learning could also strengthen teamwork. Thus, students agreed that teaching materials with the STEM-PjBL integrated TPACK model could make learning Physics more interesting and enjoyable.

#### 4. Conclusion

Physics teaching materials with STEM-PjBL (Science, Technology, Engineering, Mathematics and Project-based Learning) model integrated with TPACK (Technological Pedagogical Content Knowledge) are very valid, practical, and statistically effective for improving students' problem-solving skills.

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