Analysis TPACK framework in ISLE-based STEM approach model: case study

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Abstract. TPACK is a framework that integrates technological knowledge, pedagogical knowledge, and content knowledge in a learning context. This article discusses the analysis of the TPACK framework in the application of the ISLE-based STEM approach for the case of mass-spring oscillations. The successful application of the ISLE-based STEM approach model in learning activities must start from increasing the TPACK ability. However, TPACK and ISLE-based STEM information are currently still limited, so it is necessary to conduct a study to analyze the TPACK relationship through the development of ISLE-based STEM learning instruments. This research was conducted based on the development of learning media, namely a prototype of spring vibrations using MEMS and IoT technology as well as student worksheets designed with an ISLE-based STEM approach model by the STEM Research Center of Universitas Syiah Kuala. The analysis results show that the application of TPACK through the ISLE-based STEM model approach requires a complex process. This information is a step in the development and assessment of ISLE-based STEM learning media on the TPACK framework to strengthen 21st-century skills.

1. Introduction

Technological pedagogical content knowledge (TPACK) is a new type of knowledge that must be mastered by teachers to be able to integrate technology properly in learning. In its development, TPACK has become a framework that can be used to analyze teacher knowledge related to technology integration in learning [1].

1.1. A framework for teacher knowledge for technology integration

The Ministry of Education of the Republic of Indonesia, through the 2013 Curriculum, requires prospective physics teachers to be able to apply technology in learning [2]. This capability is important because the world is entering the era of the industrial revolution 4.0 where information technology has become the basis of human life. The use of technology in life is a must to survive in the digital era. Not only used as a means of communication, but technology also provides many benefits to the world of education. The benefits of technology, especially in the field of physics, provide visualization of the material being taught, help the investigation process, and increase student motivation. The use of
technology in carrying out scientific investigations can strengthen students’ understanding of concepts and train students’ skills [3]. Along with the development of science and technology, the learning media used are increasingly sophisticated in the teaching and learning process. The importance of developing media is one of the determining factors for the success of learning [4]. The use of media in the teaching and learning process can change the learning atmosphere to be interesting and fun.

Figure 1. TPACK framework [1]

Integrating technology meaningfully in learning is not easy. To be able to choose the right technology, physics teachers must master the content of the science to be taught. Not only that, but teachers must also consider choosing a teaching strategy that is suitable for the technology used, this is related to pedagogical knowledge. So that to integrate technology properly, physics teachers must master the content knowledge of physics, pedagogy, and technology content. These three knowledge interact and intersect to form Technological Pedagogical Content Knowledge (TPACK) [1].

1.2. Learning physics through the ISLE-based STEM model approach

To help students understand the concepts of physics, knowledge cannot just be transferred from teacher to student. Students are subjects who have the ability to actively seek, process, construct, and use knowledge. In the learning process, students are also less encouraged to develop critical thinking skills. The various problems that arise, one of the causes is the inaccuracy of teachers in choosing learning approaches and models. The use of learning approaches and models must be able to activate students so that there are changes in students in learning activities, for that learning approaches and models must be designed properly so that learning activities can achieve optimal results.

Learning media is important in the implementation of teaching and learning activities. Therefore, all prospective teachers are equipped with the ability to arrange learning tools, including prospective physics teachers. The learning media used reflects the TPACK possessed by a prospective physics teacher. The results of the literature study show that several components of the ability to compose candidate learning tools are planning learning activities, organizing teaching materials, making assessment instruments, and choosing technology [5]. TPACK and the ability to arrange learning tools for prospective physics teachers can be improved by applying a learning model that trains PCK and is integrated with technology. The learning model referred to is the ISLE-based STEM approach model developed by a lecturer at the Faculty of Mathematics and Natural Sciences, Universitas Syiah Kuala [6][7][8][9].

STEM (Science, Technology, Engineering, Mathematics) is an approach to teaching and learning that integrates concepts and skills in science, technology, engineering, and mathematics [10]. The effectiveness of STEM involves students in discussions, experiences, discoveries to increase knowledge [11]. Learning with the STEM approach is suggested to help the success of 21st-century skills where learning through this approach is directed at encouraging students to actively explore, develop reasoning skills, and make students think critically. Also, Indonesian education is currently based on the 2013 Curriculum (K-13) which
emphasizes modern pedagogical dimensions in learning, especially physics, where students are expected to be able to dig up information through observation, asking questions, experiments, then processing data or information, presenting data or information, followed by analyzing, reasoning, then concluding, and creating [12].

In accordance with the 2013 Curriculum-based learning (K-13), to find out how these facts are formed, Euginia Etkina from Rutgers University and her colleagues developed an interactive learning approach model, known as the Investigative Science Learning Environment (ISLE) which is a learning model by creating an atmosphere learning through investigation [13][14].

ISLE helps students learn physics by engaging in processes that reflect the activity of physicists as they build and apply knowledge. This process involves observing, finding patterns, constructing and testing pattern plans, and using multiple representations of physical phenomena.

![Figure 2. ISLE Cycle](image)

2. Method
This research is a research on the development of TPACK-based learning tools which is focused on the development of technology-based mass-spring vibration prototypes and the development of Student Worksheets through the ISLE-based STEM model approach that meets valid criteria and is suitable for use. The development model used refers to the development model proposed by Plomp [16] and we reported the findings from prototyping phase and assessment phase of preliminary research. In the prototyping phase, the learning instrument was designed to suit the intended needs. Then, the readability of the instrument was assessed by some teachers and validated by experts, using the provided validation sheet.

![Figure 3. The procedures of developing the learning instrument](image)
The learning instrument was considered to be valid based on the validators’ judgment. The development was grounded in conclusive theory and the components developed were consistently linked to each other. Moreover, upon the validators’ judgment, this learning instrument was deemed to be practical as at least four out of five experts give a recommendation that the learning instrument is easy to use and the usability test showed the instrument met the relevant quality criteria.

The data analysis technique was carried out using a Likert scale [17] using four alternative answers, namely: not good = 1, less good = 2, good enough = 3, good = 4, very good = 5. Instruments that have been validated by the validator are then analyzed by using the following equation [18].

\[
\text{Percentage} \, (\%) = \frac{A}{B} \times 100\%
\]

Note: \( A \) = the score of data collection results; \( B \) = the ideal score.

The percentage results obtained are then converted into a qualitative scale based on the categories which can be seen in Table 1.

### Table 1. Media assessment criteria [19]

| No. | Score Interval       | Criteria            |
|-----|----------------------|---------------------|
| 1   | 76% ≤ P ≤ 100%       | Very good           |
| 2   | 51% ≤ P ≤ 75%        | Good                |
| 3   | 26% ≤ P ≤ 50%        | Enough              |
| 4   | 0% ≤ P ≤ 25%         | Not good            |

3. Result and Discussion

3.1. General prototype schematic (technological knowledge)

This section explains how the process of designing and making educational technology is a prototype for a simple spring oscillation experiment. The input part of the props is in the form of a MEMS (Micro Electro Mechanical Systems) sensor which functions to measure acceleration, using a Gy-521 module based on MPU 6050 with 3-axis Accelerometer (acceleration sensor) and 3-axis Gyroscope (balance regulator), or in other words 6 Degrees of Freedom (DOF) IMU. Also, the MPU6050 itself already has Digital Motion Processors (DMP), which will process the raw data from each sensor. Because the acceleration on the spring is linear, the data that is processed is only from the MEMS accelerometer sensor.

![Figure 4. The integrated LabVIEW MEMS prototype design diagram](image)

![Figure 5. MEMS prototype based on IoT](image)

The measurement results using the MEMS are read by the microcontroller and transferred to the desktop for visualization and analysis. Data transfer from the microcontroller to the desktop using WiFi...
(wireless) by utilizing a microcontroller equipped with IoT (Internet of Thing) in this study used NodeMCU ESP-12F. Previously, simple harmonic motion experiments used conventional mass springs, then the development was carried out in the form of the addition of an integrated IoT MEMS sensor which was glued to the power bank and considered a mass so that when the spring oscillated, the measurement results could be visualized on a PC using LabVIEW software [9].

By using a MEMS-based IoT prototype, students learn data transmission using wireless. Students understand how the results of teaching can be visualized. The software used can also calculate the period and frequency values automatically. Students learn a simple example of AI (Artificial Intelligence). The following are student activities using technology.

![Figure 6. The spring oscillation experiment used a MEMS-based IoT prototype](image)

![Figure 7. Visualization using LabVIEW](image)

3.2. Development of ISLE-based STEM Student Worksheets (Pedagogical knowledge)

As a teacher, how do we create a learning environment where students can find their knowledge, understand, and be able to communicate physics learning? In this study, an interactive teaching model of the Investigative Science Learning Environment or more easily referred to as the ISLE teaching model is used.

There are two main keys to this teaching model. The first key involves developing students through their ideas, through (a) observing phenomena and looking for patterns; (b) develop explanations for the patterns; (c) use these descriptions to make predictions about the test results of the experiment; (d) decide whether the results of the test experiment are consistent with predictions, and (e) revise the explanation if necessary.

Another key is to encourage students to be directly involved in the learning process by engaging in various physical activities, thereby helping them in developing productive representations for qualitative reasoning and problem-solving. The combination of these two is applied to each conceptual unit in the ISLE learning system.

Student Worksheets are designed by adding ISLE (Investigative Science Learning Environment) elements as Pedagogical Content Knowledge (PCK). PCK is an idea that presents ideas that arouse interest, which develops continuously and through experiences about how to teach certain content specially so that student understanding is achieved [20]. Student Worksheets designed based on the ISLE model syntax are the hallmarks of the pedagogical aspects of this study to support learning in schools based on the 2013 curriculum.
3.3. Simple harmonic motion learning through the ISLE model (Content knowledge)

One of the physics topics that students find difficult is simple harmonic motion. Some of the difficulties that students feel in studying the material include: students have a weak understanding of scientific terms [21]. Besides, students are also less skilled in identifying the required parameters in the calculation and they feel less confident when solving simple harmonic motion problems. Students also have difficulty determining changes in the direction of oscillating objects [22]. Another difficulty occurs when students interpret and interpret an oscillator graph [23].

Simple harmonic motion can be learned through simple pendulum experiments and spring oscillations. This paper will explain the process that students go through in extracting their knowledge to understand Hooke's Law and Newton's Second Law through the ISLE model. This learning model challenges students to act like scientists and train characters such as critical, creative, collaborative, and communicative thinking needed in 21st-century learning. The following describes the stages of learning using the ISLE model.

3.3.1. The first activity: Discovering the Concept of Quantity Intuitionally Qualitative

1. Observational Experiment: At this stage, the teacher intuitively directs students to feel the weight, the push/pull towards the center of the earth is caused by increasing loads (Concept of mass force/ gravity $F_m$). The teacher also intuitively directs the students to feel the pull and push on the spring. Where the push is in the opposite direction to the pull on the spring. (Concept of spring force $F_s$).

2. Patterns: The pattern in question is a general solution that can be reused or repeated to solve common problems. Students are directed to discuss and find patterns from the two previous observational experiments.
   a. Students find similarities and differences from the two observations above.
      - Similarity: Both feel a pull and push at the time of adding mass and increasing the length of the spring.
      - Difference: The force of mass ($F_m$) is the direction it pushes towards the center of the earth. The spring force ($F_s$) pushes it in the opposite direction to the pull.
   b. The student finds a relationship between the quantity and the conditions that change it (patterns).
      - Effect of force on the mass: $F \propto m$
      - Effect of force on the increase in spring length: $F \propto \Delta x$

In this section, students are introduced to the concept of proportionality (Model).

- Thus the concept of proportionality for the condition of mass addition becomes $F \propto m \Rightarrow F = m \cdot g$ (constant gravity). This equation is called
the Law. Newton II, who stated that an object will increase in speed if it is given a net force that is in the same direction as the direction of the object’s motion.

\[
\text{Unit } F = m \cdot g \quad [kg \cdot \frac{m^2}{s^2}] = N \ (\text{Newton})
\]

- because the direction of the pull is opposite to the direction of the force of the spring, the spring force is affected by the constant in the spring. So that \( F = \Delta x \Rightarrow F = k \Delta x \) (spring constant) This equation is also called the Hooke’s Law which states that the force exerted on an object on a spring does not exceed its elasticity limit, the increase in the length of the spring will be directly proportional to the force applied.

\[
\text{Unit } F = k \cdot \Delta x
\]

\[
k \ [N/m] = \frac{F}{\Delta x \ [m]} = N \ (\text{Newton})
\]

Students are asked to make predictions for the combined equation of the two situations above. \( F \propto m \propto \Delta x \) From the combined equation is changed to \( \frac{k}{g} = \frac{m}{\Delta x} \), where the quantities that change are \( m \) (mass) and \( \Delta x \) (increase in length/distance), while the constant quantities are \( g \) (gravitational constant) and \( k \) (spring constant). Gravity values can be seen on the web http://npsha.org/g/. While the spring constant can be calculated through experiments on the spring used.

4. Testing Experiment: At this stage students test the hypothesis they propose. The student-designed an experiment measuring the spring constant.

Student assignments:
- calculates the period of the oscillating spring with a small deviation
- calculates the period of oscillating spring with a large deviation

For theoretical calculations, use the spring oscillation formula

\[
T = \frac{1}{f} = 2\pi \sqrt{\frac{m}{k}}
\]

Are the experimental results consistent with the theoretical results? Ask students to explain the experimental results with theoretical mathematical calculation results.

Students are asked to calculate the period value manually and theoretically then match the results with the calculations obtained visually in LabVIEW \( \rightarrow \) Relationships

\[\text{Figure 8. Experimental design and connectivity} \]

It is expected that the period displayed in LabVIEW is in accordance with that obtained manually and calculations manually and theoretically. If there are differences, students need to make re-observations or submit new assumptions related to the problem.
3.4. PCK Analysis from Observer

The instrument used in this study was only to measure Pedagogical Content Knowledge (PCK) which was assessed by three observers based on a limited trial of Class X high school students.

Table 2. Student Worksheet Assessment ISLE-based STEM Approach Model

| Question                                                                 | Day-1 | Obser-ver-1 | Obser-ver-2 | Obser-ver-3 | Average |
|---------------------------------------------------------------------------|-------|-------------|-------------|-------------|---------|
| 1 Learning with Student Worksheets using the ISLE-based STEM              | 4     | 5           | 3           | 4           | 4       |
| approach model makes students understand more deeply the                  |       |             |             |             |         |
| material/concept due to the inquiry process                               |       |             |             |             |         |
| 2 Learning with student worksheets through the ISLE-based STEM            | 4     | 4           | 4           | 4           | 4       |
| model approach makes the learning atmosphere interesting and fun          |       |             |             |             |         |
| 3 Learning with the ISLE-based STEM approach model can foster             | 5     | 3           | 4           | 4           | 4       |
| scientific character in students                                          |       |             |             |             |         |
| 4 During learning using the ISLE-based STEM model, students find          | 5     | 4           | 3           | 4           | 4       |
| things that are not yet known so that students’ knowledge increases       |       |             |             |             |         |
| 5 Learning with the ISLE-based STEM model creates students who           | 4     | 5           | 4           | 4           | 4       |
| are trained to get ideas and convey them as if making students            |       |             |             |             | 4,3     |
| become scientists                                                         |       |             |             |             |         |
| 6 Student motivation increases in physics through learning with           | 4     | 4           | 5           | 4           | 4,3     |
| student worksheets using the ISLE-based STEM approach                    |       |             |             |             |         |
| 7 The ISLE-based STEM model can increase the ability of 4C                | 4     | 5           | 4           | 4           | 4,3     |
| (Critical Thinking, Creativity, Communication, Collaboration) as a        |       |             |             |             |         |
| skill needed in 21st-century learning                                     |       |             |             |             |         |
| 8 Student Worksheets using the ISLE-based STEM approach are               | 4     | 4           | 3           | 3           | 3,67    |
| easy to use/apply in schools                                              |       |             |             |             |         |
| 9 ISLE-based STEM Student Worksheets developed in accordance with the     | 4     | 5           | 5           | 4           | 4,67    |
| 2013 Curriculum                                                           |       |             |             |             |         |
| 10 ISLE-based STEM student worksheets are very interesting and            | 4     | 3           | 4           | 3           | 3,67    |
| important to apply                                                        |       |             |             |             |         |

Score | 42 | 42 | 39
Average score | 4.2 | 4.2 | 3.9
Percentage | 84% | 84% | 78%

Based on the results of the PCK assessment which was assessed by three observers using a Likert scale, the assessment of 1-5 generally the values given were in the range 3, 4, and 5. Of the ten items assessed, the average score obtained was 4.2 based on the calculation of the scores from observers 1 and 2 and 3.9 for observers 3. The assessment scores among observers were not too different, indicating that the items that were considered were not too biased. The percentage value of the three observers is in the range of 78% - 84%. Based on the media assessment criteria in table 1, it shows the student worksheet assessment ISLE-based STEM approach model is feasible and is in the very good category.

Based on the analysis of the items being assessed, the ISLE-based STEM-based student worksheets make students understand the material/concept more deeply. Observers assess that learning using the ISLE-based STEM model approach is able to make the learning atmosphere interesting and fun. Observer agrees that Student motivation increases in physics through learning with student worksheets using the ISLE-based STEM approach. The application of the ISLE-based STEM model can increase the ability of 4C (Critical Thinking, Creativity, Communication, Collaboration) as a skill needed in 21st-century learning and suitable for the 2013 curriculum. Of the three observers, one of them gave a score of 3 on the assessment related to the use of the ISLE-based STEM model student worksheets. Based on the results of the discussion conducted with the observer, it was concluded that the approaching model used was very good and very supportive in strengthening the TPACK framework, but students were still not accustomed to investigative thinking so that it needed to be habituated.
Compiling a learning plan that uses technology and meets the TPACK criteria is meaningless just inserting the use of technology in learning. The main thing in compiling learning tools using TPACK lies in the analysis of learning objectives and activities. Based on the analysis of the learning objectives that must be achieved and the learning activities selected to achieve the objectives then the appropriate technology is selected. Although TPACK starts with the letter T for technology, it does not mean that the main concern lies in technology selection, but quite the opposite. Wetzel and Marshall argue that new technology can be determined at the end of the decision-making activity, namely when the goal learning and learning activities have been determined [25].

4. Conclusion

The conclusion that can be drawn from the results of this study is that learning using the ISLE-based STEM model approach is very good and very supportive in strengthening the TPACK framework. The use of prototypes in this study provides an understanding of the participants' technological knowledge. ISLE-based STEM worksheets can improve understanding of the concept of spring vibration which is part of Pedagogical and Content Knowledge.

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