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Development of Electronic Independent Learning Activity Unit (E-ILAU) Using Project-Based Learning-STEM Integrated TPACK to Improve Higher-Order Thinking Skills

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Abstract

High-order thinking skills (HOTS) are part of 21st-century abilities. However, students still need help solving problems, especially in simple harmonic motion material, which several studies have proved to be relatively low in HOTS. Students' HOTS abilities will be trained with various learning strategies, such as a combination of teaching materials and learning models using technology. This study aims to develop an E-ILAU (Independent Learning Activity Unit Electronic) using PjBL (Project Learning)-STEM (Science, Technology, Engineering, Mathematics) integrated with TPACK (Technological Pedagogical Content Knowledge) to improve the HOTS of high school students on simple harmonic motion topics. This research and development adapts the ADDIE design with the Analysis, Design, Development, Implementation, and Evaluation stages. Data collection instruments and data analysis techniques in this study included a product validation questionnaire to determine product validity, an E-ILAU readability test questionnaire to determine product legibility before being tested, a learning implementation observation sheet to determine product practicality, and a topic of higher order thinking skills in Simple Harmonic Motion topics to find out the effectiveness of the product obtained from the pretest-posttest in terms of the results of the difference test, n-gain, and effect size. E-ILAU was implemented using a one-group pretest-posttest design. The results showed that the validity of E-ILAU was a very valid category, the readability of E-ILAU was outstanding, and the practicality of E-ILAU in learning was carried out by the lesson plan, which received a positive response from students. As well as the effectiveness of E-ILAU in the practical category of increasing higher-order thinking skills. The results showed that the PjBL-STEM-based E-ILAU integrated with TPACK was classified as valid, practical, and effective for improving the high-level thinking skills of high school students in Simple Harmonic Motion topics.

Keywords: E-ILAU, project-based learning, STEM, TPACK, higher-order thinking skills

INTRODUCTION

One of the abilities that students must possess in the 21st century is higher-order thinking skills (Amalia, Sunarno, & Aminah, 2017). However, several studies have shown that students' higher-order thinking skills still need to improve. TIMSS in Physics subjects shows that Indonesian students achieve a score of higher order thinking skills in 397, which is below the international average score of 500 (IEA, 2012). Furthermore, this result is supported by the research from Zulfiani, Suwarna, & Sumantri (2020), which shows that students' high-level thinking skills in physics are low, with an average score of 21.28. Research by Istiyono (2014) stated that high-level thinking skills for Yogyakarta high school students in physics obtained a percentage of 20.94% in the low category.

Students tend to show low-order thinking skills in physics, especially in simple harmonic motion topics. The percentage of high-level thinking skills students in the topics on harmonic vibrations is only 14% in the low category, so there is a need for strategies in learning that stimulate students' thinking repeatedly (Kusdianti, 2019). In addition, another study conducted on Christian Immanuel Pontianak High School students produced a percentage of critical thinking skills of 39% in the low category, and there are recommendations for using learning models such as problem-based learning, inquiry, and others (Ariansyah, Sitompul, & Arsyid, 2019). Research by Gracia, Maria, & Hidayatullah (2022) and Poernomo, Fariyani, & Lestari (2021) also conducted an assessment and analysis of students' higher-order thinking skills, which revealed that students only had an average score of 33.83 in the low category. The average difficulty experienced by students was 85.17%, with a very high category. Meanwhile, the higher-order thinking skills of students in Malang are relatively low in several physics materials, namely heat temperature with the results of an average student score of 0.38 for C4, 0.26 for C5, and 0.21 for C6 (Suryaningsih & Fajriah, 2020), optical geometry with an average student HOTS score of 53.57 (SD = 22.29) with the highest score of 75 and the lowest score of 25 (Sutrisno, Koes-H, & Supriana, 2018), and which is only 3.92% of students can achieve HOTS (Hasanah, Handayanto, Zulaikah, & Yuenyong 2020).

Higher-order thinking skills (HOTS) are cognitive processes that include critical analysis, synthesis, evaluation, and creativity (Jaenudin, Chotimah, Farida, & Syarifuddin, 2020). These abilities go beyond simple rote learning and information absorption; they call for higher-order cognitive processes to assess, evaluate, and apply knowledge in challenging and unfamiliar contexts. Higher-order thinking abilities are critical for success in academic, professional, and daily life because they are vital for problem-solving, decision-making, and invention. Physics is closely related to the phenomenon of daily life. Therefore, it is crucial to improve student's HOTS in physics.

The students' higher-order thinking skills on simple harmonic motion can be improved using ILAU as teaching material. ILAU is a small unit of study arranged sequentially from easy to challenging to achieve competency knowledge and skills in learning (Kemdikbud, 2017). and Joharmawan (2019) show that ILAU on electron configuration material and periodic properties of elements in increasing HOTS obtains a percentage of 91.25%, which is classified as a very valid and appropriate criterion for learning. In addition, other research shows that implementing STEM-oriented ILAU applications can improve students' higher-order thinking skills. This result is indicated by an increase in the average student learning outcomes from a score of 73 in cycle I to a score of 80 in cycle II (Aryanta, 2020). Therefore, ILAU has become an alternative teaching material for effectively training and improving students' higher-order thinking skills.

Implementing ILAU in digital form is necessary for today's era because it will make it easier for students to study anywhere and anytime (Kemdikbud, 2017). Based on the results of observations and interviews, the physics teacher at SMA Negeri 9 Malang has used ILAU as a student learning resource. However, implementing ILAU in schools only contains material and practice questions that do not sufficiently train 4C and HOTS abilities. ILAU at this school is also still in printed form, so it is less attractive to students' learning motivation.

The characteristics of learning activities that use E-ILAU are activities that lead to 21st-century abilities and foster HOTS (Kemdikbud, 2017). The skills and capabilities considered necessary for surviving in the modern world, especially in the dynamic and interconnected surroundings typical of the 21st century, are considered 21st-century abilities. These talents cover a broad spectrum of cognitive, social, emotional, and practical abilities that help people achieve in various spheres of life, such as jobs, education, and society (Arimoto & Nushizuka, 2020). In general, 21st-century skills include several factors, including critical thinking, creativity, collaboration, and communication (4C). Choosing the proper learning model is an action that could be taken to improve higher-order thinking skills. One of the appropriate learning models is project-based Learning (PjBL), which is integrated with STEM (science, technology, engineering, and mathematics). STEM is an interdisciplinary approach to education that combines all four fields into a unified learning model. STEM education strongly emphasizes using mathematical ideas, scientific principles, engineering principles, and technological developments to address issues in the real world and promote creativity (Ortiz-Revilla, Greca, & Arriassecq, 2022). The PjBL model combined with the STEM approach is an innovative step to increase effectiveness and meaning in the learning process (Diana, Yohannes, & Sukma, 2021). The steps of the PjBL-STEM learning model, according to Laboy-Rush (2011), are reflection, research, discovery, application, and communication. Research by (2021) revealed that the STEM-PjBL model effectively increased higher-order thinking skills from a pretest mean score of 66.54 to a posttest mean score of 79.26. Therefore, E-ILAU-based PjBL-STEM has the opportunity to improve students' higher-order thinking skills.

Higher-order thinking skills cannot only be trained through the PjBL-STEM model. Teachers are also expected to improve teaching quality by incorporating technology into teaching methods (Putra, Widodo, & Sopandi, 2017). Teachers are expected to understand technology that can be effectively integrated with pedagogy and content knowledge into teaching methods (Tanak, 2020). TPACK is a conceptual and structured framework that is used by teachers to design and deliver learning material content by integrating technology, pedagogic and learning material content to facilitate and assist the student learning process (Shinas, Karchmer-Klein, Mouza, Yilmaz-Ozden, & Glutting, 2015). The components of TPACK are shown in Figure 1.

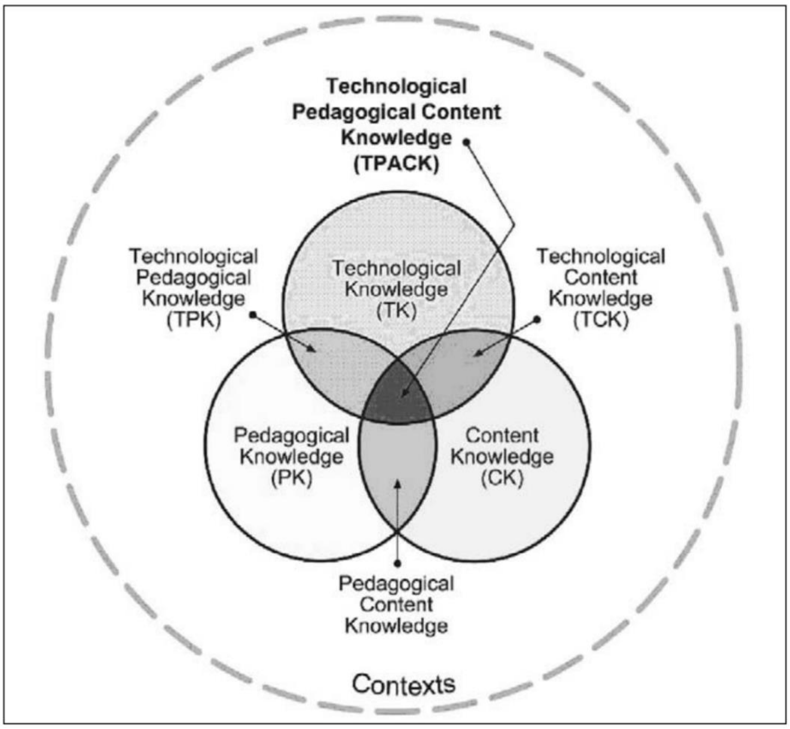


Figure 1. Diagram Venn of TPACK Components (picture from http://tpack.org)

From Figure 1, TPACK can be understood holistically from essential components in the learning process. Each element from Figure 1 can be explained through Table 1 (Schmidt *et al.,* 2009).

Table 1. Explanation of each TPACK component.

TPACK Component	Explanation
Technology Knowledge (TK)	The term "technology knowledge" refers to understanding various technologies, from digital technologies like the Internet, digital video, interactive whiteboards, and software applications to low-tech ones like pencil and paper.
Content Knowledge (CK)	The definition of content knowledge is "knowledge about the actual subject matter that is to be learned or taught." Instructors must understand the material they will teach and how knowledge differs across different subject areas.
Pedagogical Knowledge (PK)	Pedagogical knowledge encompasses lesson planning, assessment, classroom management, and student learning. It is the methods and procedures of teaching.
Pedagogical Content Knowledge (PCK)	Content knowledge about the teaching process is referred to as pedagogical content knowledge. Since pedagogical content knowledge combines pedagogy and content to improve teaching practices in the subject areas, it varies depending on the content area.
Technological Content Knowledge (TCK)	The understanding of how technology can produce new representations for particular types of material is called technological content knowledge. It implies that educators know how they might alter how students practice and comprehend ideas in a specific subject area by utilizing a particular technology.
Technological Pedagogical Knowledge (TPK)	Two examples of technological pedagogical knowledge are understanding how different technologies can be used in the classroom and realizing that employing technology may alter how teachers educate.

TPACK can be stated as one of the solutions to increase the quality of the teaching and learning process. Ilmi, Sukarmin, & Sunarno's (2020) research supports this. TPACK-based physics learning media can improve HOTS abilities and scientific attitudes with an n-gain result of 0.4 in the medium category. In general, Purwaningsih (2020) stated that TPACK could enhance the ability of prospective teachers to plan and implement technology-based learning. Therefore, E-ILAU using the PjBL-STEM model utilizing technology must be designed within the TPACK framework.

Psychologically, E-ILAU based on PjBL-STEM integrated with TPACK can train students to think at a higher level (HOTS). Activities in PjBL-STEM encourage students to design and produce a product. During design, students are also trained to think critically about the needs and urgency of the products they produce. These two skills are included in design thinking skills which are one of the indicators of HOTS (Benidiktus, 2016; Wang & Wang, 2011). To maximize the potential of PjBL-STEM in training HOTS students, teachers also need to have adequate qualities. The TPACK framework encourages teachers to learn integratively through technology, pedagogy, and content. Psychologically, implementing integrative learning enables teachers to use critical, innovative, and planned thinking, as in the HOTS component. Therefore, PjBL-STEM and TPACK must be integrated into E-ILAU.

Previous researchers have carried out several studies related to ILAU. Khasanah and Saptono (2022) succeeded in developing macromolecular ILAU to train students' cognitive abilities with a feasibility percentage of 88.4% in the valid category. Research conducted by Alfiana, R., Parno, & Yogihati (2021) succeeded in developing a PBL-STEM-based ILAU equipped with a formative assessment with a feasibility percentage of 99% and a readability percentage of 93%. So, this ILAU has an enormous potential to improve students' problem-solving skills in Temperature and Heat topics. Research conducted by Afifah and Dwikoranto (2021) succeeded in developing ILAU to increase higher-order thinking skills, with a feasibility percentage of 90% in the very valid category. However, these studies only tested the validity or feasibility of ILAU. There are limitations to this research so that this study will reveal the validity, practicality, and effectiveness of the E-ILAU.

The development of the solutions offered in this research, such as E-ILAU using PjBL-STEM integrated with TPACK, is based on two learning theories. Behaviorist learning theory emphasizes stimulus-response learning (Clark, 2018; Nélo & Nélo, 2012; Skinner, 1999). In practice, E-ILAU generally consists of a stimulus that the teacher wants to convey and a container to accommodate student responses to the stimulus that has been delivered (Madiya, 2020; Muhdhar, Wardhani, Prasetyo, Sumberartha, Mardiyanti, & Supriatin, 2021; Wardani, 2021). Thus, this E-ILAU is the application of behaviorist learning theory. In addition to behaviorism learning theory, the solutions offered are based on constructivism learning theory. This research develops E-ILAU based on PjBL, STEM, and TPACK. The three approaches are learning approaches that encourage students to construct understanding from the learning they do independently (Charania, Bakshani, Paltiwale, Kaur, & Nasrin, 2021; Petrosino, Sherard, & Tharayil, 2020; Polly & Byker, 2020). Therefore, these three elements make the developed E-ILAU based on constructivist learning theory. In other words, the solution offered implies the transition from behaviorism to constructivism in learning theory. Constructivism enables the student to actively engage in the learning process and play a significant part in creating his own body of knowledge by fusing old and new knowledge (Al-Al-Jarrah, Mansor, Hasan Talafhah, & Al-Jarrah, 2018; Jaleel & Verghis, 2015; Stapleton & Stefaniak, 2019). When this process occurs, students are indirectly trained to have higher-order thinking skills (Aseeri, 2020). Ultimately, the solutions offered can theoretically improve students' HOTS abilities.

The developed ILAU is packaged into E-ILAU. So, E-ILAU becomes easy to access and complements learning for students to understand a physics concept. This E-ILAU was created using the PjBL-STEM model and the TPACK framework, making it easier for teachers to develop teaching strategies and facilitate students' understanding. This study aims to create a valid, practical, and influential E-ILAU using PjBL-STEM integrated with TPACK to improve the HOTS of high school students in simple harmonic motion material.

METHOD

This study adapted the ADDIE research and development model (Branch, 2009). This research developed an electronic ILAU (E-ILAU) using PjBL-STEM integrated with TPACK to improve high school students' higher-order thinking skills in the topic of Simple Harmonic Motion. In this study, the development flow uses the five stages of the ADDIE model. The first stage is Analysis. This stage aims to obtain initial information and data from research subjects by seeking information about the problems studied about ILAU, HOTS, PjBL, STEM, and TPACK through literature and teacher-student interviews. The initial information and data collection technique was carried out by the researcher coming to the school to meet the teacher and several students to conduct interviews regarding the perspectives of existing learning media, like "How do you view the media used during physics lessons?". The results obtained are then narrated.

The second stage is Design. This stage is making the required product according to the initial analysis results. This stage includes developing a syllabus, lesson plans, and worksheets based on essential competencies and learning steps with the PjBL-STEM model integrated with TPACK syntax; selecting media and format according to ILAU development guidelines; and developing an instrument for assessing higher-order thinking skills on Simple Harmonic Motion topics. Syllabus development (has criteria which include the appropriateness of the content presented, the language used, selection of time allocation), lesson plan (has criteria which include the formulation of the IPKD, the appropriateness of the content presented in the form of lesson plan components and PjBL-STEM syntax, and the language used), as well as worksheets (has criteria that include content suitability, suitability for the developer, and the language used). Learning steps using the PjBL-STEM Model are integrated with TPACK in E-ILAU with assessment aspects, namely the suitability of the content in the form of E-ILAU components as well as suitability to the PjBL-STEM Model, content presentation, language, and graphics. The E-ILAU media selection developed contains text, image, video, and hyperlink content that can be connected directly to the internet. This E-ILAU was designed using Canva, which produces PDF format, then converted into HTML format using professional Flip PDF software, which produces E-ILAU, which is interactive, has interesting features, is environmentally friendly, and can be accessed at any time. The higher-order thinking skills instrument was empirically tested for each question item and then analyzed for validity, reliability, distinguishability, and difficulty level. The assessment aspects in higher-order thinking skills are C4 (analysis), C5 (evaluation), and C6 (create), with an instrument grid including (1) analyzing the characteristics of simple harmonic motion, (2) analyzing the period and frequency of simple harmonic motion (in springs and pendulums), (3) determining the equations of deviation, speed, acceleration in simple harmonic motion, and (4) analyzing mechanical energy in harmonic motion. This stage produces the initial product or Draft I of the E-ILAU.

At the development stage, the products that have been developed will be validated by two validators, such as material experts and media experts, namely physics lecturers and physics teachers. After the product has been validated, product revisions are carried out according to the validator's suggestions. The revised results of this product become Draft II of the E-ILAU. Then, Draft II of the E-ILAU was tested on fifteen students. This test is carried out to reveal the legibility of the product. The research instrument was a questionnaire assessing readability, attractiveness, and ease of use. Data analysis techniques are performed by calculating the percentage of product validity using the following formula {Formatting Citation}

$$V = \frac{\Sigma(r-l_0)}{n\,(c-1)} = \frac{\Sigma S}{n\,(c-1)} \quad (1)$$

Information:
V : Aiken index
r : scores given by experts
l_0 : lowest score in the assessment category
S : the score given by the experts minus the lowest
n : score in the assessment many experts
c : the number of categories selected by experts

Table 2. Expert Validation Assessment Criteria

Aiken index	Criteria
$V > 0{,}8$	High validity
$0{,}4 < V \leq 0{,}8$	Moderate validity
$V \leq 0{,}8$	Low validity

Then, the validity of the syllabus and lesson plans was tested, and empirical instrument questions were tested with students who had taken simple harmonic motion material. The analysis technique was carried out using a validity test, reliability test, differential power test, and level of difficulty analysis.

At the Implementation stage, the product will be implemented in one of the classes, namely X MIPA 2 at SMAN 9 Malang. This class consists of 35 students. The application of this product was carried out using a one-group pretest-posttest research design. Through this stage, practicality data was obtained by filling out the learning implementation questionnaire by the observer and student response questionnaires by students after learning. The student response questionnaire includes (1) interest in learning to use E-ILAU and (2) ease in understanding the concept of simple harmonic motion. In addition, product effectiveness can be determined based on the n-gain value from the pretest-posttest results. The practicality test data analysis technique uses the formula (1) with the following outcome criteria (Arikunto, 2009) as served in Figure 2.

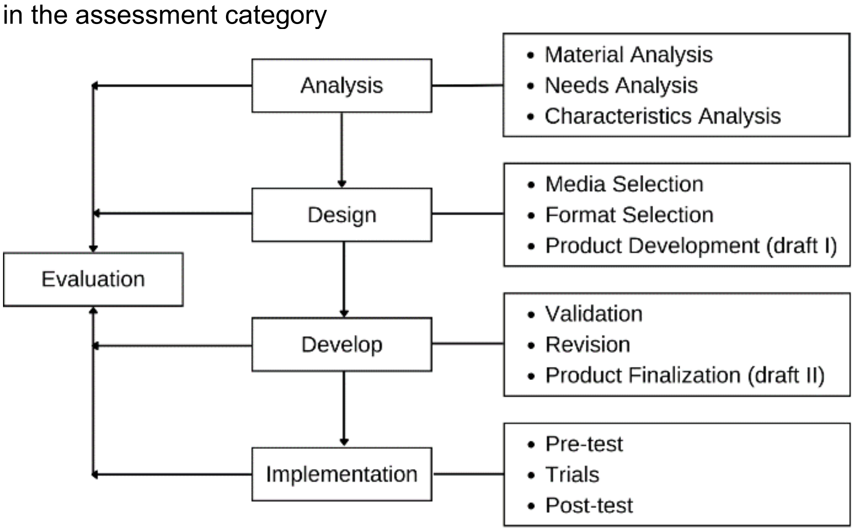


Figure 2. Development of the ADDIE model

Table 3. Product Practicality Criteria

Percentage (%)	Criteria
85 - 100	Very Practical
70 - 84	Practical
55 - 69	Pretty Practical
50 - 54	Less Practical

The analysis uses the normality test, difference test, n-gain, and effect size to test the effectiveness. The normality and difference tests were carried out using SPSS, while the following formula was used for n-gain (Hake, 1998; Sundayana, 2014a).

$$\langle g \rangle = \frac{\langle \text{post-test score} \rangle - \langle \text{pretest score} \rangle}{\text{maximum score} - \langle \text{pretest score} \rangle} \quad (2)$$

Table 4. Success Criteria based on n-gain

n-gain	Improvement Criteria
$\langle g \rangle$ < 0,3	Low
0,3 ≤ $\langle g \rangle$ ≤ 0,7	Medium
$\langle g \rangle$ > 0,7	High

For effect size use the following formula (Sada & Maldonado, 2007).

$$d = \frac{(M_l - M_B)}{SD_p} \quad (3)$$

Information:
d : effect size
M_l : average score of post test
M_B : average score of pretest
SD_p : standard deviation pooled

Table 5. Guidelines for Providing Interpretation of Effect Size Values

Coefficient Intervals	Relationship Level
0,00 – 0,20	Very low
0,21 – 0,50	Low
0,51 – 1,00	Currently
> 1,00	Strong

The Evaluation stage is carried out by conducting formative and summative product evaluations. This evaluation is carried out at the end of each of the four stages previously described.

RESULT AND DISCUSSION

The development results in this research are explained in accordance with the development procedures used.

Analysis

At the analysis stage, the first activity was to analyze the fundamental problems in this research by examining the material. This material analysis was obtained from interviews with physics teachers where the study was conducted, namely at SMA Negeri 9 Malang. This analysis activity is an interview regarding a problematic topic in class X, semester 2. One of the materials that is considered difficult is simple harmonic motion. Students are not used to associating a concept with other concepts, so they find solving complex and HOTS questions difficult.

The second activity is a need analysis. This analysis aims to determine what students need in learning, including models, methods, and learning strategies through student interviews. Based on the results obtained, students like learning using electronic-based learning media and attractive features that facilitate student learning. Learning media in digital form is necessary in the current era because it will make it easier for students to learn anywhere and anytime (Wardani, 2021).

The third activity is an analysis of student characteristics during the learning process. The results of the student character analysis were obtained from observing the activities of class X IPA 2 students during the learning process. Student behavior during the learning process tends to be passive, and he chooses silence when there are questions. Only a few students responded to questions from the teacher. In addition, when students feel confused, they have no initiative to ask questions to answer the confusion they feel. It can be concluded that students are less active in the process of learning activities, so a model or method is needed that provokes or increases students' curiosity so that later students will be active in learning, one of which is by using the PjBL-STEM model (Diana et al., 2021).

In the PjBL-STEM model, students are asked to make a project from the material studied to motivate them to discover the concepts and create projects. Based on the result data obtained from the analyze stage to overcome the above problems, the authors designed teaching materials as "Independent Learning Activity Units" packaged in electronic form using PjBL-STEM integrated with TPACK to improve higher-order thinking skills in simple harmonic motion material. E-ILAU is equipped with interesting features such as pictures, animations, videos, and virtual labs with the material being studied to make it easier for students to understand the concept of harmonic motion (Wardani, 2021).

Design

The second stage is Design. This stage is making the required product according to the initial analysis results. This stage includes developing a syllabus, lesson plans, and worksheets based on basic competencies and learning steps with the PjBL-STEM model integrated with TPACK syntax; selecting media and format according to ILAU development guidelines; and developing an instrument for assessing higher-order thinking skills on Simple Harmonic Motion topics.

The E-ILAU design was created using Canva and Flip PDF Professional software. This format enables E-ILAU to become an interactive and reversible product. Using Flip PDF Professional software can facilitate the creation of effective learning media (Pratiwi & Rachmadiarti, 2021). The developed E-ILAU is anticipated to possess several desirable characteristics, including environmental friendliness and accessibility at any time.

Table 6. Scheme of the PjBL-STEM syntax integrated with TPACK to improve HOTS

PjBL-STEM	Activity Description	Framework of TPACK	HOTS
Reflection	In the activities presented at this stage, students are introduced to the problem of simple harmonic motion through everyday life phenomena, namely earthquake disasters. Students are asked to identify issues through phenomena presented narratively.	CK	C4 (Analysis)
Research	Students are directed to look for information about simple harmonic motion from various sources at this stage. So that students understand the physics concept of simple harmonic motion, which will later be used to design a product	TPACK TCK CK	C4 (Analysis) C5 (Evaluation)
Discovery	The activities presented students with the design of a project (Earthquake Alarm) according to the concept of simple harmonic motion they have learned.	TPK PCK	C6 (Create)
Application	In the activities presented, students started creating projects and testing them.	TPK	C6 (Create)
Communication	The activities presented direct students to be able to communicate the projects that have been made and reflect on the processes and results of creating projects.	TPK	C5 (Evaluation)

In the Introduction section, students enter the Reflection stage. Students will be introduced to physics problems presented as a narrative sentence at this stage. The appearance at this stage is shown in Figure 2, where the E-ILAU content contains problems related to harmonic vibrations. This problem is picked from daily life problems regarding earthquakes and natural disasters. There are so many victims of natural earthquake disasters who do not know there are signs that an earthquake will occur. This occurs due to the absence of a tool that detects vibrations caused by earthquakes. In this problem, students are asked to make a miniature earthquake detector that applies the concept of simple harmonic vibrations. Before students are asked to make miniature earthquake detectors, students must first understand the topic of harmonic motion. This section applies the Content Knowledge (CK) component, in which the teacher utilizes theory sourced from books and the latest information about Simple Harmonic Motion topics (Tanak, 2020). In addition, this activity involves elements of Science and Technology.

In the Main section, students enter the Research stage. Students are directed to find information about Simple Harmonic Motion topics at this stage. The teacher will organize students to study. To support this activity, E-ILAU provides material consisting of sub-chapters: Definition of Simple Harmonic Motion, Restoring Force, Frequency and Period of Springs and Pendulums, Speed and Acceleration of Simple Harmonic Motion, and Mechanical Energy in Simple Harmonic Motion. An example of the display of E-ILAU at this stage is shown in Figure 3. Figure 3 shows the appearance of the E-ILAU in the Definition of Simple Harmonic Motion sub-chapter. Each sub-chapter will present apperceptions about the phenomena of everyday life to explore students' prior knowledge regarding the material to be studied. This activity involves elements of Science, Mathematics, and Technology, where students are encouraged to explain phenomena about the sub-chapters to be studied, find concepts or formulas, and search for information via the internet or conduct virtual lab experiments. In this activity, the teacher gives an initial introduction in the form of the material to be taught. This activity is the application of the Content Knowledge (CK) component, namely the delivery of material, which includes concepts, facts, and theories (Kiray, 2016). E-ILAU has image, video, and animation hyperlinks or videos sourced from YouTube. Therefore, this activity also applies Technological and Content Knowledge (TCK) to clarify the material on Simple Harmonic Motion.

Figure 3. Display of E-ILAU at the Reflection stage


UKBM GERAK HARMONIS SEDERHANA

KEGIATAN BELAJAR 1

A. PENGERTIAN GERAK HARMONIS SEDERHANA

Dalam kehidupan sehari-hari, tanpa kalian sadari banyak sekali benda-benda yang mengalami getaran. Getaran merupakan suatu benda yang bergerak bolak-balik melalui lintasan yang sama. Salah satu contoh dari getaran adalah wahana kora-kora. Wahana kora-kora merupakan salah satu wahana yang paling diminati karena ciri khasnya yang memacu adrenalin bagi orang yang menaikinya dengan bergerak bolak-balik hingga ketinggian tertentu. Getaran juga dapat disebut dengan gerak harmonis.

Gambar A.1 Wahana Kora-Kora

Suatu benda akan disebut melakukan gerak harmonis sederhana ketika benda tersebut bergerak bolak-balik secara berulang di sekitar titik setimbang. Benda yang bergerak bolak-balik di sekitar titik setimbang harmonis disebabkan oleh adanya gaya pemulih.

Gerak harmonis akan berosilasi dengan banyaknya getaran benda dalam setiap sekon selalu konstan. Benda dikatakan melakukan satu kali getaran ketika benda bergerak dari titik awal kemudian kembali ke titik awal.

Perhatikan gambar di bawah ini :

Gambar A.2 Bandul yang bergetar

Dari gambar diatas, yang merupakan :
- titik keseimbangan : R
- simpangan : R-S
- simpangan maksimum (Amplitudo) : R-T
- 1/4 getaran : P-Q-R
- 1/2 getaran : P-Q-R-S-T
- 3/4 getaran : P-Q-R-S-T-S-R
- 1 getaran : P-Q-R-S-T-S-R-Q-P

6

Figure 4. Display of E-ILAU at the Research Stage

E-ILAU also provides opportunities for students to do virtual practicums using PhET with procedures and worksheets available in E-ILAU. The use of PhET in learning is considered very effective for increasing students' understanding of concepts (Yunzal, Jr. & Casinillo, 2020). The use of PhET in education is an application of the TPACK component, where teachers use worksheets to help students find their knowledge through a virtual practicum (Rossi & Trevisan, 2018). In addition, the teacher also provides practice questions.

Furthermore, students will enter the Discovery stage, where students are guided to design a project according to the concept of simple harmonic motion they have learned. Students are instructed to find information about earthquake detectors' constituent components and working principles under simple harmonic motion through Internet sources or YouTube. This is consistent with implementing the Technological and Pedagogical Knowledge (TPK) component (Rossi & Trevisan, 2018), in which the teacher uses video technology to provide references for making an earthquake detection tool project. After finding information about earthquake detectors, students are directed to create project designs for earthquake detectors. Students are expected to be able to relate the concepts and principles of Simple Harmonic Motion with the designs to be made. This follows the application of the Pedagogical Content Knowledge (PCK) component, in which the teacher not only teaches material to students but also directs students to make decisions on the problems given (Tanak, 2020). In addition, this activity involves elements of Science, Technology, and Mathematics.

At the application stage, students begin to create and test projects. Students are asked to document all activities that have been carried out. The results of this stage are LKPD and video documentation. Both results are sent via the WhatsApp group, where teachers and students can access each other's reports. This applies to the technological and pedagogical knowledge (TPK) component, in which teachers use technology to collect student work. This activity involves elements of Science, Technology, Engineering, and Mathematics.

The final stage is the communication stage. At this stage, students present the final results of the project. Through the presentation of the project's final results, students discuss with each other through the Zoom application. This activity implements the TPK component, in which the teacher uses Zoom to present project results. After learning with E-ILAU, students are given evaluation questions to measure the level of their higher-order thinking skills. This activity involves elements of Science and Technology.

In the Closing section, students are invited to reflect on their understanding of Simple Harmonic Motion topics. In addition, students are also given follow-up instructions before heading to the next ILAU. This activity is carried out independently after the end of learning the material.

Develop

The development stage consists of expert validation, revision, and readability testing. Expert validation includes learning device validation and instrument validation tests. Validation was conducted to assess the feasibility of learning devices and HOTS ability test instruments. The products that have been developed will be validated by two validators, namely material experts and media experts, as well as physics education practitioners, namely physics teachers. After the product has been validated, product revisions are carried out according to the validator's suggestions.

Validation of learning tools and test instruments for higher-order thinking skills. The results of the validity test are presented in Table 7, Table 8, Table 9, and Table 10.

Table 7. Syllabus Validity Test Results

Aspect	Mean Score	Category
Content Eligibility	0.83	High validity
Grammar	1	High validity
Time	0.83	High validity
Mean	0.88	High validity

Table 7 shows the results of the syllabus validity test from learning using E-ILAU. Furthermore, Table 6 shows that the average value of all aspects has a percentage of 0.88, which is said to have a high validity category. The syllabus developed is adapted to the 2013 curriculum, which consists of sections (1) identity, (2) indicators, (3) learning materials, (4) learning activities, (5) assessment, (6) time allocation, and (7) learning resources. Mulyasa (2010) states that the syllabus is the design of subjects on specific topics developed by each educational unit consisting of competency standards, basic competency (KD), indicators of basic competency achievement (IPKD), learning materials, assessments, time allocation, and learning resources. This explanation supports that the syllabus is based on the theory, so the syllabus is suitable for use in learning.

Table 8. Lesson Plan Validity Test Results

Aspect	Mean Score	Category
Formulation of Indicators	0.72	Moderate validity
Content Eligibility	0.75	Moderate validity
Grammar	0.91	High validity
Mean	0.79	Moderate validity

Table 8 shows the results of the lesson plan validity test from learning using E-ILAU. Furthermore, it shows that the average value of the learning plan (lesson plan) assessment in all aspects has a percentage of 0.79, which is said to have a moderate validity category.

Table 9. Student Worksheet Validity Test Results

Aspect	Mean Score	Category
Content Suitability	0,86	High validity
Compatibility with Developers	1	High validity
Grammar	1	High validity
Mean	0.95	High validity

Based on the results of the lesson plan assessment by the validator, the lesson plan design was developed according to the guidelines for developing 2013 curriculum learning tools, namely Permendikbud Number 81A. The lesson plans must consist of indicators, learning objectives, learning materials, methods, learning resources, and an assessment of learning outcomes (Kemdikbud, 2017). Table 9 shows the results of the student worksheet validity test from learning using E-ILAU.

Before being tested, the lesson plan was assessed, and suggestions were made for improvement. A lesson plan that has been corrected becomes a guide in carrying out learning activities. It shows that the average value of all aspects has a percentage of 0.95. So, the student worksheet compiled has a high validity category for usage in learning.

Table 10. E-ILAU Validity Test Results

Aspect	Mean Score	Category
Content Eligibility	0.51	Moderate validity
Presentation	0.58	Moderate validity
Grammar and Graphics	0.83	High validity
Mean	0.64	Moderate validity

Table 10 shows the results of the E-ILAU validity test. This indicates that the content eligibility aspect has a percentage of 0.51, with a moderate validity category. According to BNSP (2014), the category of eligibility for content must pay attention to the material, accuracy of the material, and up-to-date and contextual. The material's content must support the achievement of learning objectives so that the media used can achieve these goals. On the other hand, the Presentation aspect obtains an average value of 0.58 with moderate validity criteria. BNSP (2014) reports that the feasibility of presenting a book requires looking at presentation techniques, supporting material presentation, learning presentation, and learning completeness. The preparation of the topic's content must be coherent and systematic to help students think coherently.

The grammar and graphics aspect gets a superior average score of 0.83, with a high validity category. Using communicative and easy-to-understand language in E-ILAU helps students to understand the material more easily. BNSP (2014) reports that book content should be informative, trigger communication between users, and be proper to students' level of thinking. Pay close attention to the selection and arrangement of words or sentences is necessary because they can affect the purpose of delivering material to students. This can affect the reading interest and understanding obtained by students. Overall, the validity of the developed E-ILAU has an average percentage of 0.64 with a moderate validity category.

Several factors support E-ILAU to get a score with very valid criteria. The first factor is the E-ILAU component developed under the ILAU development guidelines. Second, the use of communicative and easy-to-understand language in E-ILAU and the ease of using E-ILAU can be accessed at any time so that students can learn independently every time. Third, the contents of the learning E-ILAU are systematically arranged and closely related to implementing the material in everyday life.

Before being applied to students, an empirical test was carried out on the items to determine the pre-test and post-test questions' feasibility. The results of the empirical test items are presented in Table 11.

Table 11. Items Empirical Test Results

Analysis	Question Item	Skor	Category
Validity	1, 2, 3, 4, 5, 6, 7	≥ 0,34 (r table)	Valid
Reliability	1,2,3,4,5,6,7	0,859 ≥ 0,81	Reliable
Discriminating Power	1, 3, 4, 5, 6, 7	≥ 0,4	Good
	2	≥ 0,2	Medium
Difficulty Level	1, 2, 3, 4, 5, 7	≥ 0,26	Medium
	6	≥ 0,76	Difficult

Table 11 shows that the question items on the E-ILAU have a valid and reliable category. Discriminating Power shows that most of these items have an excellent ability to distinguish students' abilities. On the other hand, the Difficulty Level shows that only one item has difficult criteria.

Apart from validating learning tools and high-level thinking ability test instruments, the instruments also tested the readability of E-ILAU, obtained from the results of the E-ILAU readability questionnaire, which revealed three aspects: readability, attractiveness, and ease of use. This readability questionnaire was filled in by 15 students from one of the state high schools in Malang. The results of students' readability of E-ILAU are presented in Table 11.

Based on the data presented in Table 11, the assessment of the Readability aspect of the E-

ILAU is in a Very Good category with a percentage of 84.75%. This shows that images, videos, and simulations in E-ILAU are presented clearly and can be appropriately used, thus helping students understand the material. In addition, the language used is easy to understand. Assessment of the attractiveness aspect gets a percentage of 85%. This shows that the appearance of the E-ILAU is presented with an interesting color formulation, thus fostering student interest and motivation to use the Simple Harmonic Motion E-ILAU.

Table 12. Results of students' readability of E-ILAU

Aspect	Mean Score Percentage (%)	Category
Readability	84.75	Very Good
Attractiveness	85	Very Good
Ease of use	89.75	Very Good
Average	86.5	Very Good

Assessment of the ease of use of E-ILAU gets a percentage of 89.75%. This shows that E-ILAU is very practical and easy to access, thus helping students understand concepts. Overall, students' assessment of the developed E-ILAU can be categorized as a feasible product for learning.

Implementation

In the implementation stage, the product that has been validated and revised will then be implemented into learning. This implementation was carried out for class X students at SMAN 9 Malang. The purpose of implementing this product is to determine its practicality and effectiveness.

Table 13. Observation Results from the Implementation of Learning.

	1st Meeting	2nd Meeting	3rd Meeting
Mean Score Percentage (%)	86.87	85.4	83.33
Category	Very Practical	Very Practical	Practical

The practicality of a product refers to the learning implementation plan (lesson plan) activity, which is obtained through the observation of the implementation of learning by applying TPACK Integrated PjBL-STEM-based learning, which is assessed by two observers, namely a physics teacher and one student. Observation results from the Implementation of Learning are presented in Table 13.

Based on Table 13, the assessment results of the learning implementation for three meetings using the PjBL-STEM-based E-ILAU obtained a mean score percentage of 85.2% with a Very Practical category. In addition, the results of student responses to learning through questionnaires obtained 82.56% with a Practical category. It can be concluded that the implemented E-ILAU has practical value so that it can be implemented properly in learning. Implementing the entire syntax of the TPACK-integrated PjBL-STEM model is important to achieve the desired goal, namely to increase higher-order thinking skills so that they can identify the effectiveness of the E-ILAU that has been developed.

The effectiveness of E-ILAU can be seen from the pretest-posttest questions tested on X-MIPA 2 class students with seven questions. The pretest-posttest questions were given to 35 students. This effectiveness test is reviewed from the paired sample t-test, n-gain, and effect size test. However, before that, a normality test was carried out using Shapiro-Wilk analysis to determine the data distribution. The normality test results are presented in Table 14.

Table 14. Normality Test Results

Score	Shapiro Wilk		
	Statistics	Df	Sig.
Pretest	0.953	34	0.127
Posttest	0.943	34	0.062

Table 14 shows that the Pretest and Posttest data have a Sig value. > 0.05, namely 0.127 and 0.062, respectively. So, it indicates that the two data are normally distributed. After both data were declared normally distributed, a paired sample t-test was conducted to see the differences in students' higher-order thinking skills before and after using the PjBL-STEM-based E-ILAU. The results of the paired sample t-test obtained a significance value of 0.000 (Sig. <0.05). This value indicates a significant difference between students' higher-order thinking skills before and after using E-ILAU. Improving higher-order thinking skills is done by analyzing the n-gain score of the pre-test and post-test values. The results of the analysis of students' improvement scores can be seen in Table 15.

Table 15. N-gain Test Results

Pre-test Mean Score	Post-test Mean Score	N-gain	Category
52.18	79.75	0.58	Medium

Table 15 shows that the increase in students' higher-order thinking skills is in the medium criteria with an n-gain of 0.58 (Hake, 1998; Sundayana, 2014b). TPACK Integrated PjBL-STEM-based E-ILAU significantly influences students' high-order thinking skills in simple harmonic motion material. This is evidenced by acquiring an average high-order thinking skill with an average pretest score of 52.18 and a posttest average score of 79.75. This is in line with what was stated by Sambite, Mujasam, Widyaningsih, & Yusuf (2019): PjBL-STEM learning can improve students' higher-order thinking skills. This is because, with PjBL-STEM, students are actively involved in the learning process, so students' interest and motivation in learning increase. In addition, using PjBL-STEM-based teaching materials improves higher-order thinking skills (Novalia, 2022). Lukitasari, Handhika, & Murtafiah (2018) state that PjBL-STEM can direct students to analyze, evaluate, and create a product. These series of activities enable students to achieve higher-order thinking skills.

After that, an effect size test was conducted to determine how much the applied E-ILAU affects the students. The results of the effect size test are shown in Table 16.

Table 16. Effect Size Test Results

Mean (Post-test and pre-test)	Std. Deviation	Effect Size
27.5714	9.1012	3.029

Table 16 shows an effect size value of 3.029, obtained in the strong category. Thus, the E-ILAU that has been developed is effectively used in learning to improve students' high-level thinking skills in Simple Harmonic Motion topics. The following are examples of student answers on the pretest and posttest.

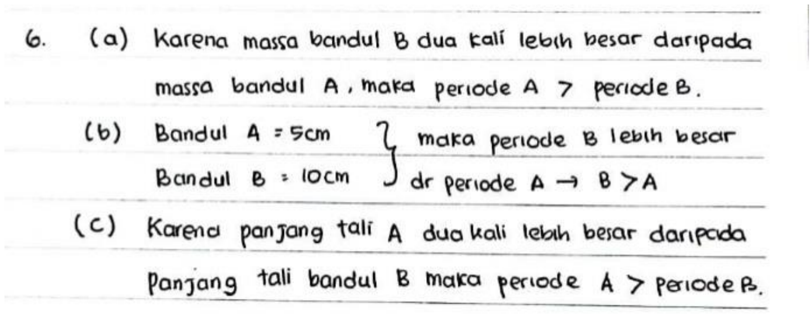
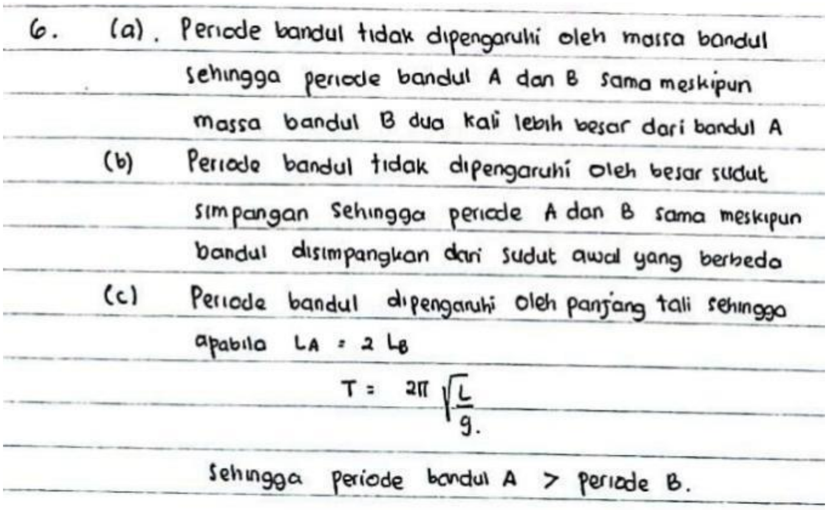


Figure 5. Simple harmonic motion pretest results
(Answer in English: 6 (a) The mass of pendulum B is twice as large as the mass of pendulum A, so the period of A is greater than the period of B; (b) Period B is more significant than period A; (c) The length of pendulum string A is twice as long as the length of pendulum string B, so the period of A is greater than the period of B)



6. (a). Periode bandul tidak dipengaruhi oleh massa bandul
sehingga periode bandul A dan B sama meskipun
massa bandul B dua kali lebih besar dari bandul A
(b) Periode bandul tidak dipengaruhi oleh besar sudut
simpangan sehingga periode A dan B sama meskipun
bandul disimpangkan dari sudut awal yang berbeda
(c) Periode bandul dipengaruhi oleh panjang tali sehingga
apabila $L_A = 2 L_B$

$$T = 2\pi \sqrt{\frac{L}{g}}.$$

Sehingga periode bandul A > periode B.

Figure 6. Simple harmonic motion posttest results
(Answer in English: 6 (a) The period of the pendulum is not affected by the mass of the pendulum so that the periods of pendulum A and pendulum B have the same value; (b) The period of the pendulum is not affected by the size of the deviation angle so that the periods of pendulum A and pendulum B are the same; (c) The period of the pendulum is influenced by the length of the string so that the period of pendulum A is greater than the period of pendulum B)

Based on the result of student interviews after using the TPACK-Integrated PjBL-STEM-based E-ILAU in learning, students admitted that they needed to become more familiar with the PjBL-STEM model with project-based learning. They also have never solved a matter of higher-order thinking skills in physics. In addition, the physics teacher also explained that previously conducted learning was only carried out using the conventional model supported by conventional ILAU, which only contained material and practice questions. The above constraints significantly affect students' higher-order thinking skills in physics learning.

Even though several factors constrained it, the ability to think at a higher level increased in the moderate category. Several factors caused this improvement. The first factor is learning using E-ILAU with the PjBL-STEM model, which is learning that solves authentic problems in an interactive, collaborative, and unique way. Therefore, this learning can train students' thinking skills, increase understanding of the topics studied, help maintain the knowledge learned, and improve students' abilities to apply abilities to real-world problems through the projects they work on (Bergh *et al.,* 2006).

The second factor is applying technology, pedagogy, and content aspects in using E-ILAU. These three aspects act as a unified learning framework that integrates ICT into the learning process and transmits this knowledge to students. Teacher innovation in using ICT is needed, one of which is by packaging teaching materials in electronic form that can be accessed at any time. In addition, E-ILAU can be equipped with multimedia, such as pictures and videos, that interest students in learning. The application of technology to teaching materials and the physical learning assessment process has a positive impact on teachers and students (Baihaqi, Purwaningsih, Sulur, & Sutopo, 2022; Kurniawan, Kusairi, Puspita, & Kusumaningrum, 2021).

CONCLUSION

E-ILAU using PJBL-STEM with integrated TPACK helps students learn simple harmonic movement material. From the results of the research data, the validity of E-ILAU was 0.64 in the moderate validity category, and the reliability of E-ILAU was 86.5% in the reliable category. 85.2% of the practicality of E-ILAU in learning was carried out according to the lesson plan, and a positive response was received from students. Apart from that, E-ILAU using PJBL-STEM with integrated TPACK can help improve high-level thinking skills in simple harmonic motion material. This was obtained from the results of E-ILAU effectiveness being in the effective category for improving high-level thinking skills with an n-gain of 0.58 in the medium category and an effect size of 3.029 in the strong category. It can be concluded that E-ILAU using PJBL-STEM with integrated TPACK is a valid, practical, and effective teaching material for improving high-level thinking skills. E-ILAU can be used and distributed to support learning and enhance high-level thinking skills on simple harmonic movement material. Based on the research results, it is suggested that further research be carried out using this E-ILAU. Further researchers could also prove that this developed E-ILAU is properly used in other samples or populations to improve students' HOTS skills.

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