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Improving the skills of prospective elementary teachers in designing earth and space science digital teaching materials: TPACK framework

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Abstract: This study aimed to improve the skills of prospective teachers in designing interactive Earth and Space videos prepared for teaching at the elementary school level by integrating Earth and Space Science lecture programs based on the TPACK framework. This research used an experimental method with seventy-five students participating in the study. The lecture program was based on adaptation to the seven components of TPACK. The research instruments consisted of a questionnaire with seven components of TPACK and a rubric to asses the product, a teaching material developed by prospective teachers. The results showed an increase in the TPACK competence of prospective teachers in the medium category. In addition, the TPACK framework-based lecture program practiced prospective teachers' skills in making teaching materials in several aspects in good categories: presentation, management content, and integration of pedagogical and technology. The statistical analysis showed that there is a positive relationship between the perception of TPACK and the ability to make digital teaching materials for prospective teachers

Keywords: Digital Teaching Material, Earth and Space Science, Prospective Elementary Teachers, TPACK Framework

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INTRODUCTION

The development of online learning in recent years, especially during the pandemic, has created new problems that must be addressed, especially for elementary school teachers. The main problem is the teachers' low ability to provide teaching materials integrated with technology (Andarwulan et al., 2021) and low digital literacy skills (Hamdani & Priatna, 2020). Meanwhile, the teacher should be able to organize online learning that has good quality in growing student achievement, motivation, and learning behavior.

The ability to develop teaching materials is a fundamental skill that should have by the teacher, and it is related to pedagogical competencies. (Handayani & Jumadi, 2021; Handayani et al., 2021). Hence, the teacher should be able to develop teaching material to become a professional teacher. This competence will be tested when there is a change in the learning environment from traditional to digital learning, which causes teachers to be more creative. As we know, there are fundamental differences between online and offline learning. Furthermore, teachers must improve their ability to compile teaching materials from paper to digital. With suitable online teaching material, the learning will be more meaningful and help students master content and concepts more quickly (Handayani et al., 2021; Santhalia & Sampebatu, 2020; Wati et al., 2022).

Learning science is not only about the product of knowledge like facts, concepts, or principles from teacher to students. Teachers should practice students finding and exploring knowledge by providing learning experiences, for example, discovery learning and problems solving. Through the right learning experience, students will have valuable thinking skills for solving problems through various activities, i.e., reading books, researching, and observation (Maison et al., 2020). However, this activity cannot be carried out optimally when the learning environment changes from face-to-face in class to online learning. There will be many obstacles because teachers cannot guide students directly, and students must study independently (Handayani & Jumadi, 2021). Additionally, teachers and students

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are not familiar with online learning; on average, they still have low technological literacy, especially learning technology (Saputri, 2021). Integrating technology into the learning process is needed to efficiently maximize the online science learning process (Anggara et al., 2021).

Teachers' difficulties in online science learning must be a common concern, especially for teacher education universities. This concern is not only about the pandemic but also about preparing teachers who can adapt to the increasingly rapid development of online learning. Teacher education universities need to respond by developing a lecture model that prepares prospective teachers to integrate technology into the learning process while also considering the pedagogical aspects—for example, pushing the prospective teacher to develop digital teaching materials. Through well-designed digital teaching materials, a teacher can facilitate students to conduct practical learning activities by utilizing integrated multimedia consisting of audio, video, animation, images, and text. In addition, digital teaching materials can also be equipped with practice questions and interactive quizzes to examine student understanding. Mastering technology and content material are not enough to develop digital teaching materials; it is also necessary to involve pedagogic aspects to match learning concepts.

The learning approach that can help students develop skills in integrating technology, pedagogy, and content knowledge is the TPACK framework (Mishra & Koehler, 2006). This framework is a new version of Pedagogical Content Knowledge (PCK) (Shulman, 1986, 1987) with a technology touch. In TPACK, teachers need to combine three components of core knowledge that are technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK). From the three core knowledge, three first-level combined knowledge can be formed, namely technological content knowledge (TCK), technological pedagogical knowledge (TPK), and pedagogical content knowledge (PCK), which is a combination of two core knowledge. In addition, the three core knowledge can also form the second level of combined knowledge, namely technological pedagogical content knowledge (TPACK). It is the most complex of knowledge because the three core knowledge are integrated.

The TPACK framework has been widely used to practice teachers' skills to integrate digital technologies in educational contexts (Ching Sing Chai et al., 2013; Hew et al., 2019). The previous study has been used TPACK as an approach to practice teachers' professional skills in technology integration in learning to prepare learning plans (Akyuz, 2018; Ching Sing Chai & Koh, 2017; Dalal et al., 2017; Joyce Hwee Ling Koh et al., 2017; Tseng et al., 2019), microteaching practice (Ching Shing Chai et al., 2010; Durdu & Dag, 2017; Tokmak, 2013), and instructional media design (Koh & Divaharan, 2011; Özgün-Koca et al., 2011). The previous divided the TPACK framework in the professional teacher's training. First, teachers are given direct training in using several specific technology applications, and second, teachers are given the freedom to apply technology.

This study will use the TPACK framework to develop an earth sciences lecture program to equip prospective elementary school teachers with the skills to develop digital teaching materials. The integrated technology emphasized developing interactive videos for learning earth and space sciences. Prospective teachers are not given direct video processing software and practice but are encouraged to study independently by utilizing video tutorials on YouTube and actively exchanging ideas with their classmates. Based on this background, the research questions are:

RQ1: Does the TPACK-based lecture program improve prospective elementary teachers' perceptions of integrating technology and pedagogy into developing digital teaching materials?

RQ2: How is the interactive video of earth and space science quality after attending the TPACK-based lecture program regarding content management, technology, and pedagogy integration?

RQ3: Is there a positive correlation between prospective elementary teachers' perceptions of integrating technology and pedagogy and the quality of the product?

METHOD

Research Design and Procedures

The research method used an experimental design. This method determined the causal relationship between the independent and dependent variables (Creswell, 2012). This study was initiated by pre-testing prospective teachers' self-assessments of integrating technology, content, and pedagogy in digital teaching materials. After that, students followed the TPACK-based earth and space science course program for 12 meetings. All meetings in the lecture program were designed so that students could develop TPACK skills independently, as has been done in several studies (Chen & Jang, 2018;

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Tantrarungroj & Suwannatthachote, 2012). After receiving treatment, a post-test was conducted to determine the increase in prospective teachers' self-assessment of the ability to integrate pedagogy, content, and technology in digital teaching materials. In addition, prospective teachers were also asked to make digital teaching material products in the form of interactive earth and space science videos to be used in learning in elementary schools that focus on three aspects: management of material content, pedagogical aspects, and integration of technological support.

Research Subject

The subject of this study was 75 students, or prospective elementary teachers, of the Elementary School Education Program, University of Muhammadiyah, Prof. Dr. Hamka, who attended earth and space science lectures.

Research Instrument

Two instruments used in this study were used to answer the research questions: a TPACK questionnaire and observation sheets.

The TPACK questionnaire

The instrument was used to obtain information about the self-assessment of prospective teachers' skills to integrate content, pedagogy, and technology in a digital teaching material product. There are 25 statements from 7 TPACK aspects, as shown in Table 1.

Table 1. TPACK's ability perception self-assessment grids

No	TPACK Aspect	Indicator
1	Technology Knowledge (TK)	• Using image processing applications • Using sound processing applications • Using video processing application • Using animation processing applications
2	Pedagogical Knowledge (PK)	• Use various learning strategies • Modify learning according to objectives • Determine appropriate learning strategies. • Adjust teaching methodology
3	Content Knowledge (CK)	• Develop earth and space science materials with appropriate concepts • Select earth and space science concepts that are suitable to the student's level • Plan the sequence of earth and space science concepts to be taught • Make connections between earth and space science concepts
4	Technology Pedagogical Knowledge (TPK)	• Create a technology-rich learning environment • Apply different teaching methods with technology. • Use technology to train students' thinking skills. • Motivate students to use technology.
5	Pedagogical Content Knowledge (PCK)	• Differentiate various learning strategies for different earth and space science concepts. • Develop learning strategies to anticipate possible student misconceptions in earth and space science learning. • Develop learning strategies to help students connect earth and space science concepts
6	Technology Content Knowledge (TCK)	• Use a variety of technological representations to demonstrate earth and space science concepts. • Implements earth and space science materials contained in the curriculum using technology. • Use various online programs for learning earth and space science.
7	Technology Pedagogical Content Knowledge (TPACK)	• Using technology to help students understand earth and space science concepts • Use technology to expand the representation of earth and space science content in textbooks. • Fulfilling the demands of learning earth and space science contained in the curriculum using technology.

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The Observation Sheets

An observation sheet was used to explore students' ability to create technology-based earth and space science teaching materials in the form of interactive video learning based on four indicators: material content management, integrating pedagogy, applying technology, and presentation display. The assessment guide is shown in Table 2.

Table 2. TPACK integration assessment grid in digital teaching material products

No	Aspects	Indicators
1	Material Content Management	• The earth and space science material presented follows the correct concept. • The depth and breadth of the earth and space science material presented are appropriate for the level of the students. • Earth and space science material presented following the demands of the curriculum
2	Integrating Pedagogy	• The method of delivering earth and space science material according to the level of student competence • The method of delivering earth and space science material supports 21st-century thinking skills • The method of delivering earth and space science material supports student learning motivation
3	Applying Technology	• The technology used supports students' better understanding of earth and space science concepts • The technology used supports 21st-century thinking skills • The technology used supports student learning motivation
4	Presentation View	• Earth and space science material, technology application, and pedagogy are presented harmoniously and support each other. • Presentation of earth and space science materials, application of technology, and application of pedagogy support a better understanding of student concepts • The presentation of earth and space science materials, technology applications, and pedagogy applications is broader than just what is displayed in the textbook.

Data Analysis Techniques

To answer research question 1 (RQ1), the data analysis technique used is the N-gain test (Hake, 1998) with equation 1.

$$<g> = \frac{\%<G>}{\%<\mathrm{G}>_{\max}} = \frac{\left(\%<S_f> - \%<S_i>\right)}{\left(100 - \%<S_i>\right)} \quad (1)$$

S_f is the post-test score, S_i is the pre-test score, and $<g>$ is the N-gain. Furthermore, the N-gain score classifies into three categories, as seen in Table 3.

Table 3. Interpretation of Normalized Average Gain

<g>	Category
<g> > 0,7	High
0,3 < <g> < 0,7	Medium
<g> < 0,3	Low

The product assessment results and interpreted according to the criteria in Table 4 to answer the RQ2.

Table 4. Percentage division of the categories

Percentage (%)	Category
0 - 50	Very poor
51 - 60	Poor
61 - 70	Fair
71 - 80	Good
81 - 100	Excellent

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Finally, to answer RQ3, the data was analyzed using the Pearson correlation test with the following equation.

$$r_{xy} = \frac{n\sum XY - (X)(Y)}{\sqrt{\left\{n\sum X^2 - \left(\sum X\right)^2\right\}\left\{n\sum Y^2 - \left(\sum Y\right)^2\right\}}} \quad (2)$$

X is the prospective teacher perception, and Y is the product quality. Furthermore, to determine the correlation level between the two tested variables, the r_{xy} score obtained is then interpreted according to the criteria presented in table 5.

Table 5. Interpretation of Correlation

<g>	Category
$0.00 < r \leq 0.19$	Very Low Correlation
$0.20 < r \leq 0.39$	Low Correlation
$0.40 < r \leq 0.59$	Moderate Correlation
$0.6 < r \leq 0.79$	High Correlation
$0.8 < r \leq 1.00$	Very High Correlation

RESULT AND DISCUSSION

Implementation of TPACK-based Earth and Space Science Lecture Program

Earth and space sciences is a compulsory course in the department of primary school teacher education that is intended for students taking the science program. This course talks about natural phenomena that may be difficult to meet directly in real-world situations because of the limited time of occurrence and the distance of observation. Hence, several simulation videos, animations, computer models, etc. used to study earth and space sciences phenomena.

This course aims to provide an understanding of the concepts of earth and space science as one of the science sub-materials taught in elementary schools. In addition, this course also aims to prepare prospective elementary school teachers to design a learning activity to re-teach the concept of earth and space according to the level of elementary school students by utilizing various technological features. Thus, it is necessary to design a lecture program to enable elementary school teacher candidates to integrate technology into elementary school earth and space learning by creating digital teaching materials using the TPACK framework.

The lecture program is structured based on three levels of the TPACK framework, where at the first level, three essential competencies are introduced, namely content knowledge (CK), pedagogic knowledge (PK), and technological knowledge (TK). In the next stage, the lecture program is designed by integrating two of the three basic knowledge, namely pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), and technological content knowledge (TCK). In the last stage, the lecture program is designed to combine three aspects of basic knowledge, namely technology pedagogical content knowledge (TPCK), into a digital teaching material product in the form of interactive learning videos. The TPACK-based earth and space science lecture program in 12 meetings are arranged in the order shown in Table 6.

Table 6. Steps for the TPACK-based Earth and Space Science Lecture Program

Step	TPACK Aspect	Activities
1	Content Knowledge (CK)	Students compile earth and space science materials with the appropriate breadth and depth of material based on the results of the analysis of the Basic Competencies and Learning Indicators contained in the Primary School curriculum.
2	Pedagogical Knowledge (PK)	Students analyze and discuss innovative learning models/methods/strategies that can be used in distance learning science learning in elementary school.
3	Technology Knowledge (TK)	Students analyze various forms of literacy/technology skills that need to be mastered by teachers in the digital era that can support learning activities

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Step	TPACK Aspect	Activities
4	Technology Pedagogical Knowledge (TPK)	Students analyze various forms of technology support appropriate for the application of distance learning models/methods/strategies in science learning in elementary schools and discuss them in lectures.
5	Pedagogical content Knowledge (PCK)	Students choose one of the topics of earth and space science material in elementary school and then develop a learning scenario that includes a description of the material along with the integration of the application of innovative learning models/methods/strategies that can be used to teach the material.
6	Technology Content Knowledge (TCK)	Based on the chosen topic of earth and space science material in elementary school, students then analyze various forms of technical support that can be maximized to improve the quality of learning on these materials and discuss them in lectures.
7-12	Technology Pedagogical Content Knowledge (TPACK)	• Students design storyboards as a guide for developing digital teaching material products in interactive learning videos that integrate pedagogy, content, and technology appropriately. • Students develop digital teaching material products in the form of interactive learning videos that can be used to conduct distance learning in an asynchronous form • Students present the products that have been made to get feedback and suggestions from lecturers and colleagues as material for product improvement • Students make revisions based on suggestions, and inputs received to improve the products produced

The steps for implementing a TPACK-based lecture program that will be used are the development of an existing framework, namely the MAGDAIRE framework (Chien et al., 2012), which consists of (1) modeled analysis, (2) guided development, (3) articulated implementation, and (4) reflected evaluation. The MAGDAIRE framework was developed to integrate science learning with technology in general. Hence, if the framework is used in prospective teacher lectures, there will be weaknesses were developing material on teaching materials may not be aligned with the curriculum. Furthermore, a new framework was developed to analyze material content according to the curriculum and integrate pedagogical elements in designing teaching materials.

Perception of Prospective Elementary School Teachers on the Integration of TPACK

The description of the students' initial TPACK self-assessment data is presented in Table 7. Based on Table 7, it can be seen that there was an increase in the average TPACK ability score from 66.15, which was included in the medium category, to 76.73, which was in the high category.

Table 7. Descriptive statistics on TPACK ability from pre-test and post-test results

Descriptive Statistics	Pretest Score	Posttest Score
Number of Students	75	75
Mean	56.02	76.16
Standard Deviation	4.67	3.02
The Highest Score	80.60	100.00
The Lowest Score	58.50	65.22

The increase in each TPACK indicator can be seen in Figure 1.

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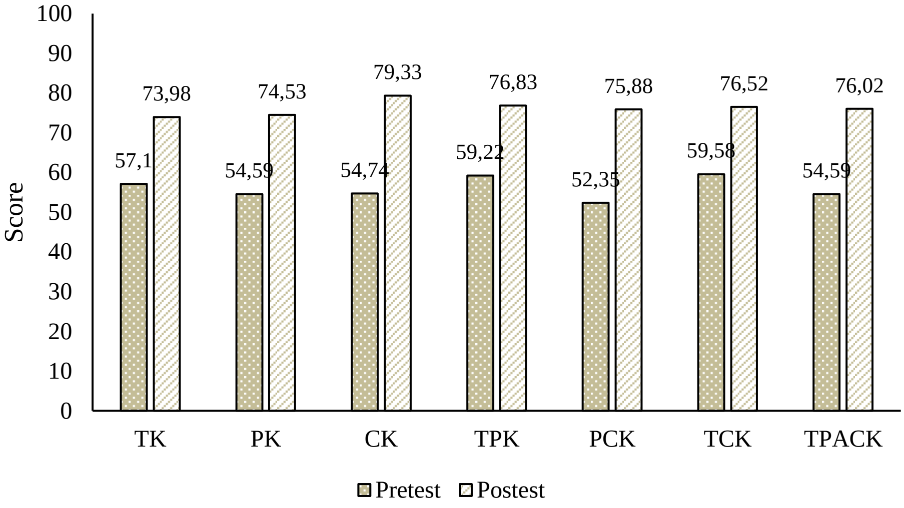

Figure 1 Comparison of the average scores in each aspect of TPACK

According to Figure 1, there is an increase in each TPACK indicator after the TPACK-based lecture is applied. The N-gain test is carried out, as shown in Table 8.

Table 8. N-Gain Test Results on Each Aspect of TPACK

No	TPACK Aspect	Pre-test	Posttest	<g>	Interpretation
1	Technology Knowledge (TK)	57.10	73.98	0.39	Medium
2	Pedagogical Knowledge (PK)	54.59	74.53	0.44	Medium
3	Content Knowledge (CK)	54.74	79.33	0.54	Medium
4	Technology Pedagogical Knowledge (TPK)	59.22	76.83	0.43	Medium
5	Pedagogical Content Knowledge (PCK)	52.35	75.88	0.49	Medium
6	Technology Content Knowledge (TCK)	59.58	76.52	0.42	Medium
7	Technology Pedagogical Content Knowledge (TPACK)	54.59	76.02	0.47	Medium
	Average	**56.02**	**76.16**	**0.46**	Medium

Based on the previous explanation, the arranged TPACK-based lecture program is intended to make students independent in developing the three components of TPACK core knowledge and first-level and second-level combined knowledge. Based on the data analysis, it was found that all TPACK components experienced an increase in the medium category. However, if we look at the <g> value, it appears that the highest increase is in the content knowledge aspect (CK), and the lowest increase is in the Technology knowledge aspect (TK). This result is in line with previous research (Chen & Jang, 2018; Tantrarungroj & Suwannatthachote, 2012), where the increase in technological knowledge is low because this knowledge is difficult to learn alone, collaboration is needed in the form of support from experienced teachers for novice teachers (Tricarico & Yendol-Hoppey, 2012). Based on the analysis results, we can also see that the low level of technological knowledge (TK) is followed by low combined skills involving technological knowledge such as TPK and TCK. As for the high increase in content knowledge, because knowledge of material content is the easiest knowledge to learn independently by finding information from various sources. This knowledge is more of an inculcation of cognitive aspects that can be built on their own compared to technological and pedagogical knowledge which is closer to the aspects of skills that need to be built from the process of training and experience. This is in line with independent learning theory which states that independent learning ability is closely related to cognitive achievement (Zheng et al., 2018).

Earth and Space Science Interactive Video Product

Furthermore, based on the assessment of teaching material products made by students, the description of students' skills in developing digital teaching materials based on TPACK aspects is presented in Table 9. Based on Table 9, it can be seen that the average student skills in making digital teaching materials of 74.42, which is in the excellent category.

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Table 9. Descriptive Statistics of Skills in Developing Digital Teaching Materials

Descriptive Statistics	Score
Number of Students	75
Mean	74.42
Standard Deviation	7.21
The Highest Score	87.50
The Lowest Score	56.25

The increase in each indicator of the assessment of teaching materials products can be seen in the following picture:

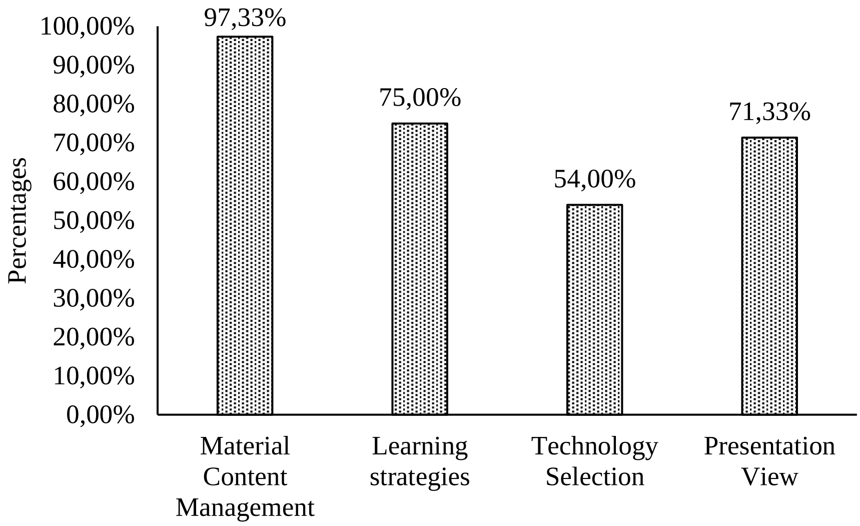

Figure 2. The average score on each aspect of the development of interactive earth and space science videos

Based on Figure 2, it can be seen that prospective teachers' ability to make technology-based earth and space teaching materials included in the less category is in the ability to choose the right technology for teaching materials. Then the suitability of selecting learning strategies for teaching materials is in a suitable category. Finally, in managing material content, students' abilities are excellent. This result is in line with the self-assessment of the TPACK skills of prospective teachers, where prospective teachers feel their technological abilities are low, which is also proven in the products produced that do not involve appropriate technology. Likewise, in the aspect of material management, in line with the results of the TPACK self-assessment, students can produce teaching material products that have good material management because an excellent conceptual understanding supports them. Some examples of the resulting teaching materials are shown in Figure 3, which is a screenshot of the resulting teaching materials.

Based on the analysis, overall teaching materials made by prospective teacher students have met the TPACK elements in the good category. These results indicate that the application of the TPACK-based lecture program has a good effect on the ability to compose digital teaching materials, although the technological aspect still has to be improved to make it even better.

Furthermore, based on the Pearson correlation test between prospective teachers' self-assessment perceptions of TPACK skills and the ability to develop interactive videos of earth and space science, a correlation coefficient value of 0.71 was obtained, which is in the high correlation category. This shows a high correlation between the perception of prospective teachers' self-assessment of TPACK abilities and the ability to create digital teaching materials. The Pearson correlation test analysis results produced a positive correlation coefficient value, indicating that if a prospective physics teacher has a high perception of TPACK, then the prospective teacher has a high digital teaching ability. This result is in line with several studies that report that a person's perception of TPACK will be reflected in the quality of the learning tools he makes (Amrina et al., 2022; Harris & Hofer, 2011; Sholihah et al., 2016).

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Integrating TPACK into digital teaching material product development activities such as interactive videos of earth and space science in research is not only done by using various technological devices in it. The essential thing in integrating technology in the preparation of teaching materials is to analyze the material's content and the objectives to be achieved from the activities to be carried out, which raises the need for technological integration (Harris et al., 2010). Although in the TPACK framework, the term technology is denoted by the letter T at the front, it does not mean that the use of technology is the basis used to determine other aspects, but instead, the technological aspects are determined last after the content, and pedagogical aspects are determined first (Wetzel & Marshall, 2011).

Figure 3. Prospective elementary school teachers produced screenshots of interactive earth and space science videos.

CONCLUSION

In this study, we applied the TPACK framework to the earth and space science lecture program to improve the ability of prospective elementary teachers to develop digital teaching materials on earth and space science materials in elementary schools. The TPACK framework-based lecture program's application has proven to significantly increase the perceptions of prospective elementary teachers about integrating technology and pedagogy into the development of digital teaching materials on earth and space science materials in the medium category. It also has a positive impact on the ability of teachers to develop digital teaching material products in the form of interactive videos of earth and space science for learning in elementary schools in terms of content management aspects, integration of pedagogical aspects, appropriate use of technology and presentation of teaching materials which on average are in the excellent category. The correlation test shows that there is a positive relationship between TPACK perceptions and the ability to create digital teaching materials, which indicates the perceptions of prospective elementary school teachers about the integration of technology and pedagogy into the

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development of digital teaching materials on earth and space science materials will increase along with the increasing ability to develop digital teaching materials.

However, this study has limitations. The teaching materials produced at this time are only in the form of interactive learning videos on earth and space science materials in elementary schools, which focus on assessing the integration of content, pedagogy, and technology. Researchers have not focused on measuring potential aspects to increase student learning motivation because, after all, the presentation of learning in a digital environment that aims to create an independent learning environment for students also needs to pay attention to aspects of motivation generation as a trigger so that students have an interest in learning. Finally, through this research, we hope to provide insight for teachers and teacher education researchers to continue innovating in lecture programs to prepare science teachers in the digital era.

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