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Eulerian Graph in STEM Learning Approach : Local Instruction Theory for Prospective Mathematics Teacher

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Abstract: This study aims to design a LIT of Eulerian graphs based on the STEM learning approach. By combining LIT with the STEM approach, teaching Eulerian graph material can be done in a more applicable and easily understood way by prospective mathematics teacher students. This study is a design research study with three stages, preliminary design, design experiment, and retrospective analysis. The trial was conducted on fourth-semester prospective mathematics teacher students of the Mathematics Education Department, Faculty of Education and Teacher Training, IAIN Kerinci. The instruments used were validation sheets and student response questionnaires. The analysis was carried out quantitatively and qualitatively. Based on data analysis, it was found that 1) The stages carried out to obtain a LIT of Eulerian graphs based on the STEM learning approach consisted of preliminary design (analyzing subjects, setting objectives, literature review, compiling HLT, and expert validation), design experiments (pilot experiments and teaching experiments), and retrospective analysis. 2) Local instruction theory of Eulerian graphs based on the STEM learning approach is practically applied in learning with a practicality percentage of 88% which is categorized as very practical. The application of LIT in learning Eulerian Graph with the STEM approach shows positive results in improving the mathematical understanding of prospective mathematics teacher students.

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Introduction

Graph theory is a branch of mathematics that studies vertices (nodes) and the edges that connect them (Blanco & García-Moya, 2021). Graph theory is used to solve problems in various fields such as computer science, urban planning, network modeling (telecommunications), ecosystem modeling and genetic networks (biological research), education, and network analysis in social, healthcare and fraud detection (Hlinenko et al., 2023; Jafari et al., 2023; Kostić et al., 2020; Saputro & Prihatin, 2023; Sari & Mohamad, 2021). In mathematics education, graph theory is very important as it fosters logical thinking and problem-solving skills (Ferrarello et al., 2022; Prayitno et al., 2022; Uyangör, 2019). One of the important and interesting topics in graph theory is Eulerian graphs because they can be used to solve various real-life problems (Fischer et al., 2012). Eulerian graphs are a type of graph used in fields such as network analysis, scheduling, and computational biology, this type of graph has a path that visits each edge exactly once (Dorn et al., 2013; Huang & Lai, 2007; Jafari et al., 2023; Tran et al., 2022). The application of Eulerian graphs in real-world problems, such as garbage collection, is an example of how useful applications can be used as teaching tools to enhance understanding (Nkuna, 2023). In the field of mathematics education at the university level, Eulerian graphs are material that must be studied in graph theory and discrete mathematics courses. So, understanding Eulerian graphs is essential for prospective mathematics teacher students.

Despite the importance of graph theory, particularly Eulerian graphs, many students at the university level struggle to understand this material (Blanco & García-Moya, 2021; González et al., 2021; Güler, 2016; Uyangör, 2019). This difficulty also occurs for prospective teachers, who must not only have knowledge and understanding of Eulerian graphs, but also be able to teach them to students. Many prospective teachers struggle with proofs and abstract reasoning, especially due to the transition from high school to university-level mathematics (Geisler & Rolka, 2020). There are several mistakes made by prospective mathematics teacher students in solving Eulerian graph problems, mistakes in determining the shortest path, performing calculations that are not in accordance with the given algorithm and mistakes in providing justification and also the right reasons (Aziz, 2021; Harisman et al., 2023; Medová et al., 2019). This also happens to prospective mathematics teacher students at the Department of Mathematics Education IAIN Kerinci. Based on observations of prospective mathematics teachers at the Department of Mathematics Education IAIN Kerinci, it was found that there are still many prospective mathematics teacher students who are unable to determine the right strategy in solving Eulerian graph problems, are unable to apply concepts, and lack strong motivation to solve these problems. The low understanding of prospective mathematics teachers in learning Eulerian graphs is partly due to inappropriate learning approaches, so that they do not have a clear understanding of how Eulerian graphs can be applied to real-world problems (Nabiyev et al., 2016). Thus, an innovative learning approach is needed so that prospective mathematics teachers can understand Eulerian graphs well.

One of the innovative and problem-solving-oriented learning approaches is the STEM (Science, Technology, Engineering and Mathematics) learning approach. STEM is a learning approach that combines and integrates various disciplines such as science, technology, engineering, and mathematics to be applied in learning activities (Aguilera et al., 2021). STEM approach learning aims to develop the ability to solve complex problems and think critically which are important skills that prospective teachers should have (Çalışıcı & Sümen, 2018). This approach can develop a deep understanding of mathematical concepts through experimental activities, solving problems and collaborating with peers (Eshaq, 2024).

Some previous studies have shown the success of applying the STEM approach in learning. STEM integration in mathematics learning can increase the activeness of prospective teachers because there are activities based on investigation and practice (Marfuah & Khikmawati, 2023). The STEM approach can influence the identity of prospective mathematics teachers by increasing their confidence to learn mathematics and teach mathematics (Dodsworth, 2019). In addition, the application of the STEM approach in learning can improve critical thinking, creative thinking, problem-solving, reasoning, collaboration, and motivation (Joseph & Uzondu, 2024; Putri & Juandi, 2023; Rahmawati & Juandi, 2022; Yusuf et al., 2022; Zakeri et al., 2022). Research shows that successful implementation of the STEM approach requires authentic learning contexts that connect mathematical concepts with real-world applications (Dare et al., 2018; Kelley & Knowles, 2016). This approach allows prospective mathematics teacher students to engage in problem-centered learning, enhancing their understanding of how mathematics interacts with other disciplines such as science and engineering. Learning with the STEM approach is expected to be able to develop the abilities of prospective mathematics teacher students in understanding Eulerian graphs. In order to provide maximum results, lecturers need to design Local

Instructional Theory (LIT) using the STEM learning approach, especially on the Eulerian Graph material. A lecturer needs to design learning through LIT as a guide in teaching the material at the university level (Cárcamo et al., 2019).

LIT is a theory about learning activities that include a description of the learning flow on a particular topic and supporting tools in the learning process (Gravemeijer & van Eerde, 2009). The LIT consists of learning objectives, planned learning activities, assumptions and anticipated student responses (Nickerson & Whitacre, 2010). Through LIT, the lecturer can identify difficulties experienced by prospective mathematics teacher students during learning and can anticipate actions to overcome these difficulties (Cárcamo et al., 2019). LIT provides a framework for lecturers to design effective learning that develops students' understanding of mathematics (Cárcamo et al., 2019; Nickerson & Whitacre, 2010). In learning Eulerian graphs, lecturers can design learning activities from simple concepts to complex concepts, so that prospective mathematics teachers can build their understanding gradually.

LIT is the result of a Hypothetical Learning Trajectory (HLT) that has been designed or compiled, tested and evaluated (Nickerson & Whitacre, 2010; Prahmana & Kusumah, 2016). In other words, to develop LIT on a particular material topic, the first thing that must be developed is HLT. HLT is a theoretical framework for designing learning that hypothesizes the learning process (Simon, 2014). HLT consists of three components, learning objectives, learning activities, and hypothesized learning process (Baroody et al., 2022; Simon, 2014). HLT aims to guide educators in implementing learning to improve students' abilities (Yuliardi & Rosjanuardi, 2021). HLT must be developed through several stages such as design, testing, and implementation, so that the final result becomes LIT.

Several previous studies have shown that LIT supports and is effective for educators to design learning that is in accordance with cognitive development, so that it can foster an understanding of the concepts learned (Arimbi & Hiltrimartin, 2022; Doorman, 2019; Meika et al., 2019; Purnomo et al., 2021). In addition, the use of LIT in learning integrated with innovative learning approaches has proven to improve problem-solving, logical thinking, mathematical communication and strategic competence (Amsari et al., 2022; Armiati et al., 2022; Fauzan et al., 2020; Hered et al., 2021; Nuraida et al., 2018; Supriatna et al., 2017). These studies focus on the development of LIT integrated with realistic mathematics education and contextual teaching and learning approaches at the primary and secondary school levels. There is no study that combines LIT with the STEM approach on Eulerian graph material at the university level.

This study aims to design a LIT of Eulerian graphs based on the STEM learning approach. By combining LIT with the STEM approach, teaching Eulerian graph material can be done in a more applicable and easily understood way by prospective mathematics teacher students. This approach provides an opportunity for prospective mathematics teacher students to not only understand Eulerian graphs in the context of theoretical mathematics, but also in its application in everyday life or in other disciplines. The novelty of this study is the development of LIT that integrates the STEM context in learning Eulerian graphs. There have been no previous studies that specifically develop LIT based on the STEM approach for graph theory material for prospective mathematics teachers. This study provides a new contribution by presenting a learning design that does not only focus on mathematical aspects, but also emphasizes the connection between graph concepts and the real world, technology, and engineering, which has rarely been touched in mathematics education. Thus, lecturers can apply LIT in learning graph theory and discrete mathematics, especially on Eulerian graph material. In addition, LIT on Eulerian graph material developed in this study can be a reference for lecturers to develop LIT on other materials.

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Through this LIT, it is hoped that prospective mathematics teacher students will not only gain theoretical knowledge about Eulerian graphs, but also skills in delivering the material in a way that is more interesting and relevant to students in the future. This study is expected to make a wide contribution to the development of theory and practice of mathematics learning at the university level, especially in learning graph theory and discrete mathematics for prospective mathematics teacher students.

Research Method

This study is categorized as design research. Design research is a research method designed to develop learning theories and activities, in this case developing LIT through a process of repeated design, implementation, and reflection (Gravemeijer, 2004). The procedure for developing this LIT consists of three steps as follows:

Preliminary Design

The stage in the preliminary design is the initial stage in preparing the design. This stage consists of activities to analyze the subject, determine the purpose of design development, review the literature, and compile the HLT. In the activity of analyzing the subject, an assessment of initial abilities is carried out. Based on the results of the subject analysis, the objectives of the design and literature review are then determined. The next activity is to compile the HLT. In designing the HLT, supporting instruments are needed in the form of a Semester Learning Plan (RPS) and teaching materials.

Teaching Experiment

After the HLT is compiled, the next step is to conduct a trial. Before the trial is carried out, the HLT, RPS and teaching materials are validated first. After the HLT, RPS and teaching materials are declared valid, the next step is to carry out the design trial stage. The trial is carried out in two stages. At the pilot experiment stage, HLT was applied to limited subjects consisting of 11 students with different abilities. After the HLT and instruments were revised, a teaching experiment was conducted. At the teaching experiment stage, learning was carried out based on the revised HLT. The results of this revision became the LIT.

Retrospective Analysis

At this stage, reflection was carried out on the results of the HLT trial at the teaching experiment stage. Furthermore, improvements and revisions were made based on the results of the observations.

The trial at the pilot experiment stage was carried out on 11 students in Mathematics Education Department, Faculty of Education and Teacher Training, IAIN Kerinci. The trial at the teaching experiment stage was carried out on all students who were attending the graph theory course. The data in this study consisted of observation data and questionnaires. Observation data were obtained from observation sheets during the HLT trial. Questionnaire data were taken from questionnaires filled out by prospective mathematics teacher students during the product trial.

The data collection instruments used were validation sheets, observation sheets, and questionnaires. The validation sheet was used by the validator in providing suggestions and assessments regarding HLT, RPS and teaching materials through the validation sheet. To determine the suitability between HLT and the implementation of learning, an observation sheet was used. The questionnaire was given during the trial. The analysis was carried out quantitatively and qualitatively. Qualitative analysis was used to analyze data obtained from the results of validation to experts or validators, observation results and interviews with trial subjects. The results of qualitative data analysis will be a guide for making product improvements. Quantitative data analysis is data from questionnaires to determine the

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practicality of the product being tested, both in group trials at the pilot stage and in teaching experiments.

Results and Discussion

This study was conducted using the design research method consisting of three steps, namely preliminary design, teaching experiment, and retrospective analysis. The following is a description of the results of the research conducted.

Preliminary Design

Preliminary design is the initial stage that must be carried out because at this stage the problems found in the graph theory lecture process are studied and then a method for solving the problem is formulated. The steps taken at this stage are analyzing the subject, determining the purpose of design development, reviewing the literature, compiling HLT along with supporting instruments and validation to experts. Based on the results of the subject analysis, many prospective mathematics teachers showed limited understanding of the basic concepts of Eulerian graphs, especially related to the concepts of connected graphs, Eulerian paths, and Eulerian circuits. Thus, it is necessary to design LIT to overcome these problems. This is the basis for designing LIT Eulerian graphs based on the STEM learning approach.

Teaching Experiment

1). Pilot Experiment

This pilot experiment aims to improve the quality of the designed HLT. The pilot experiment was carried out on 11 prospective mathematics teacher students studying graph theory. There were four activities carried out at the experimental stage, namely: confirming the understanding of the Eulerian graph as well as semi-Eulerian and non-Eulerian graphs, finding the characteristics of Eulerian and semi-Eulerian graphs, finding the Fleury algorithm, solving the postman problem.

The results of the pilot experiment obtained information that before prospective mathematics teacher were asked to learn they had to know the benefits or uses of the knowledge they would learn so that they would be more enthusiastic about learning it compared to being given theory directly. This was seen when in between discussions in the group there were 2 people who asked "What is this for?". In addition, lecturers must provide more anticipation of the possibilities of prospective mathematics teacher responses that occur. Because during the pilot experiment, the anticipation provided was not yet able to overcome prospective mathematics teacher responses to the activities provided.

After the learning activities were carried out, prospective mathematics teacher were given a questionnaire to assess the practicality of HLT in learning Eulerian graphs. Based on the results of the questionnaire analysis, it is known that the percentage of HLT practicality at the pilot experiment stage as a whole is 85% which can be categorized as very practical. Therefore, HLT can then be tested at the teaching experiment stage after being revised.

2). Teaching Experiment

Activity 1

In activity 1, prospective mathematics teachers are expected to be able to confirm their understanding of Eulerian graphs as well as semi-Eulerian and non-Eulerian graphs. Prospective mathematics teachers are given 6 graphs and they are asked to classify which ones are Eulerian, semi-Eulerian and non-Eulerian graphs. Of the 11 students, 9 of them were able to quickly classify the given graphs based on the existing categories, the other 3 students were slower in making classifications of the given graphs. But after being asked questions (does the first graph match the first definition? If so, what is the graph called? If not, try to match it with the second and third definitions, which one is more appropriate?) as anticipation, they were able to classify the given graphs based on the existing categories.

Activity 2

This activity aims for prospective mathematics teachers to be able to find the characteristics of Eulerian and semi-Eulerian graphs. In this activity, more than half of the prospective mathematics teachers were unable to distinguish problems when given a directed graph. They simply equate directed and undirected graphs in determining the characteristics of the Eulerian graph. In anticipation of this response, prospective mathematics teachers were reminded: to try to pay attention to whether the given graphs are the same. Is there no influence of direction on a graph with Eulerian graph characteristics?

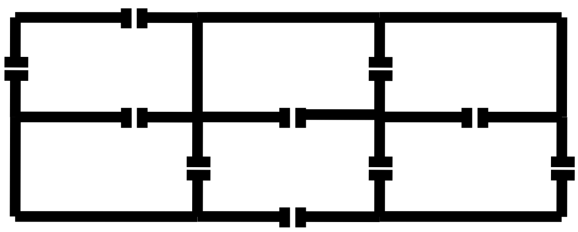
Activity 3

In activity 3 the goal is for prospective mathematics teachers to be able to find the Fleury algorithm. Prospective mathematics teachers are given Eulerian graph and they are asked to find the Fleury algorithm. To find the Fleury algorithm, many prospective mathematics teachers are still confused about what they should do first. In STEP 1 almost all prospective mathematics teachers can determine the starting point but after continuing to STEP 2 they are confused about choosing an edge so that STEP 3 cannot be continued. This is a response to the activity given, for this response an anticipation is given in the form of a question. Which edges are connected to the starting point you choose? Can we choose one of several edges connected to the starting point to make a trail?

Activity 4

In activity 4 the goal is for prospective mathematics teacher to be able to solve the postman's problem. Prospective mathematics teachers are divided into 3 groups with each group consisting of 3-4 people and the lecturer tells the postman's problem. How he has to deliver letters every day and the next day there are more letters or packages that come to the office to be distributed again to the destination address, if you don't have a strategy in distribution then the letters will pile up because there is not enough time to deliver the letters. From the problem, prospective mathematics teachers are asked to find an effective way to distribute the letter using the concept of graph theory that has been studied. After prospective mathematics teachers can find an effective way to the postman problem, they are given another problem that is similar to the postman problem. This activity is included in science, prospective mathematics teachers are asked to conduct experiments to solve the problems given. The following are the problems given.

The image below is a floor plan of a building. Is it possible to walk through each door on that floor only once if we are allowed to start from any door? Then turn the path into a graph!



To make this activity more interesting, a styrofoam board, nails for styrofoam, colored paper and ribbons are provided to make the sides of a graph. In the activity given at the second meeting, the three groups initially looked confused and thought without doing anything with the tools that had been given. The prospective mathematics teacher students' responses were given anticipation by asking questions such as: can you find the path that will be taken by imagining it without trying to make the path? Don't you need a new picture that you can try to

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describe the path that will be taken? The following is a picture of the results of the prospective mathematics teacher's work in determining the path that will be taken as shown in Figure 1.

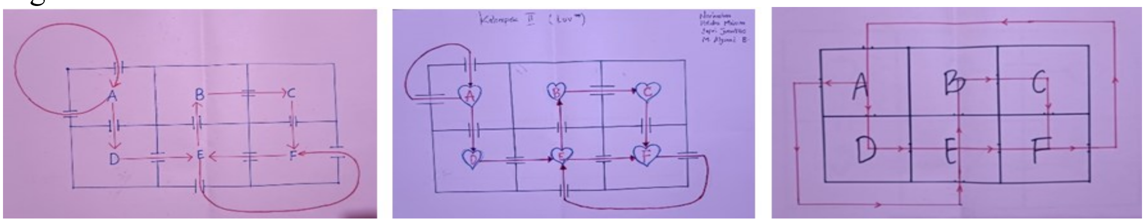

Figure 1. Answers from prospective mathematics teacher students to the questions given

After finding the path to be taken, prospective mathematics teachers construct it in the form of a graph using styrofoam as a base, then cut paper to make vertices or points and use ribbons to make the sides of the graph. As seen in the following picture in Figure 2.

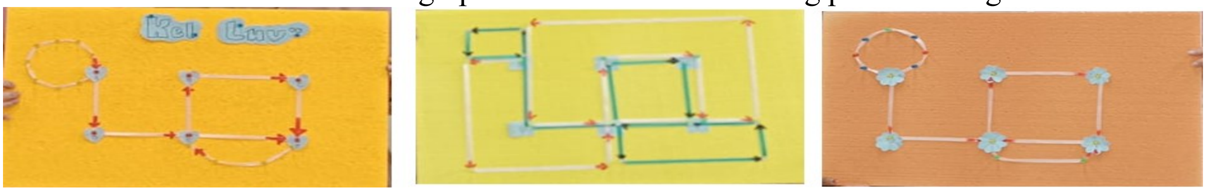

Figure 2. Answers to the Problems Given on Styrofoam

This activity is included in engineering and mathematics. Starting from them designing a road that will be passed (including engineering) then from the road they made it was changed into a mathematical model in the form of a graph (including mathematics). After completing the given problem, prospective mathematics teacher students create a graph image using applications or technologies that they know to visualize the graph so that it is easy to understand such as using the GeoGebra and PowerPoint applications. This activity is included in technology. Each group presents the results of their group work in front of the class.

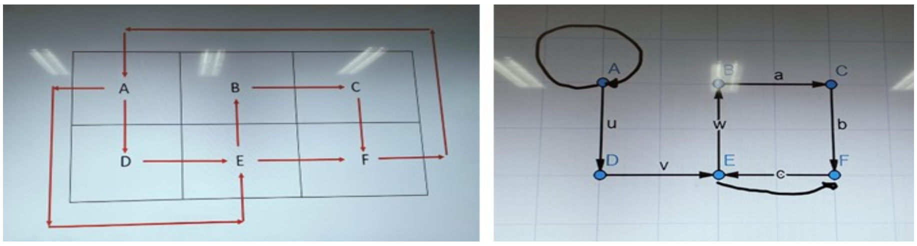

Figure 3. Prospective mathematics teacher students use GeoGebra and PowerPoint to present their results

After the learning activities at the teaching experiment stage were carried out, prospective mathematics teachers were given a questionnaire to assess the practicality of HLT in learning Eulerian graphs. Based on the results of the questionnaire analysis, it is known that the percentage of HLT practicality at the teaching experiment stage as a whole was 88% which can be categorized as very practical. Thus, it can be said that the HLT that was prepared is practical to be applied in learning the Eulerian graph material.

Retrospective Analysis

Retrospective analysis is a comparative analysis between the learning design designed at the preliminary design stage with the data obtained in the teaching experiment. The description of the activities carried out during learning to develop mathematical abilities is explained as follows. At the first meeting, prospective mathematics teachers were able to understand the definition of the Eulerian graph well. Some prospective mathematics teachers had difficulty in determining the characteristics of the Eulerian graph from the example graphs that had been given. However, overall, prospective mathematics teachers were able to understand the concept of the Eulerian graph well. At the second meeting, obstacles still occurred during the pilot experiment, but during the teaching experiment, the number of prospective mathematics teacher who experienced obstacles was not as many as during the pilot experiment. There are still prospective mathematics teachers who are confused about constructing the Eulerian circuit on a Eulerian graph using the Fleury algorithm and there are still those who are confused about what to do first when they are asked to find a travel route in a building. Overall, prospective mathematics teachers can learn well, there are still obstacles but not as many as during the pilot experiment. At the teaching experiment stage, the assumptions that have been made at the preparing stage appear to be implemented even though there are some of the prospective mathematics teacher students' cognitive processes that are beyond expectations. In the second meeting, there was a group trying to create an idea about a travel route on a floor of a building with 2 routes at once.

The application of LIT based on the STEM approach in learning Eulerian graphs has a positive impact and has proven effective in helping, prospective mathematics teachers understand complex concepts such as Eulerian graphs. LIT allows for more contextual and adaptable learning according to prospective mathematics teacher's needs, which is very important in the context of learning for them (Cárcamo et al., 2019). Before implementing the STEM approach, many prospective mathematics teachers showed limited understanding of the basic concepts of Eulerian graphs, especially related to the concepts of connected graphs, Eulerian paths, and Eulerian circuits. However, after implementing LIT in learning, prospective mathematics teachers showed significant improvements in their understanding. Many prospective mathematics teachers were able to identify and explain the properties of Eulerian graphs more easily after engaging in contextual and applicable learning activities.

LIT requires that instruction be built gradually, starting from the simplest concepts and continuing to more complex topics (Rohimah et al., 2022). In the context of Eulerian graphs, this approach makes it easier for prospective mathematics teacher to build understanding gradually, starting from the introduction of simple graphs to understanding the application of graph concepts in the real world, such as the postman problem. By integrating technology and engineering elements into learning, prospective mathematics teacher can see the relevance of mathematics in everyday life, which is the core of the STEM approach (Çalışıcı & Sümen, 2018; Stohlmann, 2019). In addition, learning with a STEM approach facilitates prospective mathematics teachers to work in groups (Julita et al., 2022; Parno et al., 2022). In this study, a prospective mathematics teachers involved in group activities, such as solving Eulerian graph problems, demonstrated the ability to work in teams and solve real problems such as Postman and finding a travel route in a building problem. This is in accordance with the goals of the STEM approach which encourages prospective mathematics teachers to be more active in solving problems that are relevant to the real world (Eshaq, 2024).

The integration of LIT and STEM not only improves conceptual understanding but also helps prospective mathematics teachers develop critical thinking and problem-solving skills. Activities in STEM-approach learning encourage prospective mathematics teachers to solve real-life problems that demand analytical reasoning and higher-order thinking processes (Priatna et al., 2020). Through activities identifying problems, determining the right strategy to solve problems, analyzing, and communicating results, prospective mathematics teachers can strengthen concept understanding and build their own understanding (Wicaksono et al., 2024). When prospective mathematics teachers are given real problems on Eulerian graph material such as postman problems and travel routes in a building, it encourages them to carry out logical reasoning in determining the right strategy to solve these problems.

Most prospective mathematics teachers gave a positive response to the use of LIT based on the STEM approach in mathematics learning. This can be seen from the questionnaire given, the percentage of practicality was 88% which can be categorized as very practical. Thus, LIT based on the STEM approach on the Eulerian graph material is practically applied in learning. By developing STEM-based LIT in the context of learning Eulerian graphs, this study emphasizes the importance of the design research approach in producing contextual and applicable theories. Conceptually, this study also expands the scope of application of the STEM approach in mathematics education. The STEM approach, which is generally used in the context of applied science, was successfully adapted to abstract mathematical topics, such as Eulerian graphs, in this study. This gives a new understanding that STEM is not limited to real contexts, but can also be applied in abstract contexts. The STEM-based learning experience developed in this study is evidence that prospective mathematics teachers need to be equipped with theoretical understanding as well as innovative pedagogical skills. From a practical perspective, this study can be a learning resource that can be used by lecturers in teaching graph theory, especially Eulerian graph material.

The STEM-based learning design developed in this study provides guidance in developing meaningful and challenging learning activities. In addition, the STEM approach used is also able to encourage the development of 21st-century skills in prospective mathematics teachers, such as critical thinking skills, creative thinking, mathematical communication, collaboration, and problem-solving, which are very relevant to current educational needs. The findings in this study can also be utilized by higher education institutions in designing mathematics learning curriculum. Furthermore, this STEM-based learning experience improves the readiness of prospective mathematics teachers to face the implementation of a curriculum that emphasizes cross-disciplinary integration and contextual approaches.

Conclusion

Based on the research results, several conclusions were obtained as follows: (1) The stages carried out to obtain local instruction theory of Euler graph based on STEM learning approach consist of preliminary design (analyzing the subject, setting objectives, literature review, HLT preparation, and expert validation), design experiments (pilot experiments and teaching experiments), and retrospective analysis, (2) Local instruction theory of Euler graph based on STEM learning approach is practically applied in learning with a practicality percentage of 88% which is categorized as very practical. The application of LIT in learning Eulerian Graphs with STEM approach shows positive results in improving the mathematical understanding of prospective mathematics teacher students. This approach not only deepens the understanding of the basic concepts of the Eulerian graph but also improves student skills and collaboration. With this approach, prospective mathematics teacher can develop solid mathematical skills while understanding the relevance and application of mathematics in the real world.

Recommendation

Based on the results of this study, it is recommended that mathematics education lecturers begin to integrate STEM-based learning approaches in teaching abstract materials, such as

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Eulerian graphs. This approach has been proven to be able to increase prospective mathematics teacher-student engagement and conceptual understanding, while bridging the understanding between mathematical theory and its application in real-world contexts. The application of LIT developed in this study can be used as a pedagogical framework in designing learning strategies that are more contextual, adaptive, and centered on the prospective mathematics teacher-student learning process. In addition, the results of the study indicate that LIT is suitable for prospective mathematics teachers. For further research, it is better to implement LIT based on the STEM learning approach to see the effectiveness quantitatively. In addition, it is better to develop STEM-based LIT for other courses and other subjects.

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