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Profile of Scaffolding Transfer in STEM-Based Open Inquiry Learning for Electromagnetics Practicum

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ABSTRACT

In the context of STEM-based open-inquiry learning, scaffolding transfer involves providing assistance that enables students to explore, experiment, and investigate problems or questions independently. The purpose of this study was to determine the profile of scaffolding transfer in STEM-based open-inquiry learning during an electromagnetics practicum. This research used a qualitative method with a participatory observation design. The research subjects were 34 students who participated in the electromagnetics practicum. The research instruments consisted of observation guides and field notes. Data were collected through direct observation during the practicum and the analysis of related documents. Data analysis was conducted through coding to identify scaffolding patterns and their transfer. The results showed that there are variations in the percentage of scaffolding provided in STEM-based open-inquiry learning on different topics. This variation reflects the dynamics of changing student needs along with the complexity of the material. These results also show that scaffolding is dynamic because the level of support can increase again when students encounter new concepts or difficult concepts. In addition, the highest scaffolding in the open inquiry process occurs at the "asking questions" stage, which indicates a great need for help at the beginning of learning. In contrast, no scaffolding was provided at the stage of "communicating the results of the investigation," which reflects students' independence.

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1. INTRODUCTION

Electromagnetic practicums in higher education are a crucial component in engineering and physics education, designed to bridge theory with practical application (Nehru et al., 2023; Wadana & Maison, 2019). Students learn fundamental concepts such as electric and magnetic fields, electromagnetic induction, and electromagnetic waves through a series of laboratory experiments. These activities involve the use of advanced equipment like oscilloscopes, signal generators, and electromagnetic circuit components, allowing students to directly observe electromagnetic phenomena. This practicum also fosters the development of critical skills such as problem-solving, data analysis, and teamwork (Lasa-Alonso et al., 2023; Zuza et al., 2018).

The electromagnetics lab is crucial for physics education students as it allows them to apply the theories they have learned in real-world contexts (Furukawa et al., 2021). By engaging in hands-on experiments, students can gain a deeper understanding of fundamental concepts such as Faraday's law, Ampère's law, and electromagnetic fields. This lab also helps them develop essential analytical and problem-solving skills in physics teaching, as well as enhance their ability to design and manage effective experiments for their future students (Bollen et al., 2015). Moreover, a solid lab experience provides them with a strong foundation to deliver material in a more engaging and relevant way, ultimately motivating students to become more interested in physics.

Electromagnetic learning and practicums often face various issues that can hinder students' understanding. One major problem is the complexity of electromagnetic concepts, which are often abstract and difficult to grasp without adequate visualization and practical application (Guihard et al., 2020). Additionally, the limitations of laboratory facilities and inadequate equipment can impede the effective implementation of experiments. The dominance of theoretical learning without being supported by relevant practicums also poses a challenge, reducing students' opportunities to connect theory with practical experience (Batuyong & Antonio, 2018; Zuza et al., 2018). Difficulties in designing experiments that align with the curriculum and the limited time available for practicums are also challenges for both lecturers and students (Guihard et al., 2020). All these factors can reduce the effectiveness of learning and impact students' ability to understand and apply electromagnetic concepts in a broader context.

Previous research has offered various solutions to address issues in electromagnetic learning and practicums. One key solution is the use of educational technology, such as computer simulations and interactive software, which has proven effective in visualizing abstract electromagnetic phenomena (Batuyong & Antonio, 2018; Ferty et al., 2019). Project-based learning approaches that allow students to be more actively involved in the learning process, linking theory with practical application through self-designed experiments, have also been effective (Mustapha et al., 2020). Additionally, collaboration between educational institutions and industry to provide access to advanced laboratory equipment and additional resources is another significant solution.

Although solutions such as the use of educational technology and project-based learning have shown positive results, their implementation is not without challenges. The implementation of educational technology, while effective, requires significant investment in hardware and software, as well as training for instructors to master the technology, which can be a burden for institutions with limited resources. Project-based learning approaches also require intensive planning and coordination, and not all instructors have the necessary experience or skills to design and implement these methods effectively.

To address these issues, this study has designed STEM-based open inquiry learning. STEM-based open inquiry learning has significant advantages in developing students' problem-solving skills. Through this approach, students are given the freedom to explore and formulate problems independently while applying knowledge from various disciplines (Pizzolato et al., 2014). This allows them to face complex situations similar to real-world challenges, enabling them to learn to think critically, creatively, and analytically (Ngabekti et al., 2019; Nivalainen et al., 2013). Furthermore, the integration of STEM in inquiry-based learning encourages students to use technology and scientific methods to find solutions, thereby strengthening their skills in systematic thinking and collaboration. Thus, STEM-based open-inquiry learning not only enhances problem-solving abilities but also prepares students to face future challenges in an innovative and integrated way (Crippen & Archambault, 2012).

Although STEM-based open-inquiry learning has many advantages, this method also has weaknesses, especially for students who lack foundational knowledge or independent learning skills. Students who are not accustomed to the open inquiry approach may feel overwhelmed by the freedom it offers, making it difficult for them to identify problems or formulate appropriate hypotheses (Pizzolato et al., 2014; Tecson et al., 2021). This can hinder the learning process and reduce the effectiveness of the method. As a solution, the implementation of scaffolding can be an effective step. With scaffolding, teachers provide gradual support, such as initial guidance, concrete examples, and guiding questions, which are then gradually reduced as students' abilities increase (Ardiyati et al., 2019). This approach helps students build the confidence and skills needed to succeed in open-inquiry learning without diminishing the exploratory essence of the STEM method itself (Tecson et al., 2021).

Scaffolding is a crucial element in STEM-based open-inquiry learning because it provides the structure and support needed to assist students in complex learning processes (Eveline et al., 2019; Tuada et al., 2020). In this context, scaffolding acts as a bridge between what students already know and what they need to achieve, allowing them to take the necessary steps to complete challenging tasks (Kyza & Georgiou, 2019; Uum et al., 2017). Through scaffolding, teachers can provide assistance tailored to the needs of each student, such as offering initial hints, asking thought-provoking questions, or providing additional resources (Burkholder et al., 2020). This helps students develop critical thinking and problem-solving skills independently, without feeling overwhelmed by the complexity of the tasks. Scaffolding can also adjust the level of support as students' abilities and confidence grow, allowing them to progress toward a deeper understanding and the capability to conduct open inquiries more independently (van der Valk & de Jong, 2009). In STEM learning, where exploration and discovery are essential, scaffolding ensures that students stay on track, promoting success and more holistic understanding.

Although there has been significant progress in research on scaffolding in the context of STEM education, there is a lack of deep understanding regarding how the transfer of scaffolding can affect electromagnetics learning, particularly in open lab settings. Many studies focus on scaffolding in structured or direct instruction-based learning, but there is a need to explore how scaffolding can adapt to more open inquiry situations and how this affects students' ability to transfer knowledge in the context of electromagnetics labs. This research aims to explain the profile of scaffolding implementation in open inquiry-based STEM learning.

2. METHODS

This research employs a qualitative method with a participative observation design. Participative observation is a data collection method in which the researcher not only observes but also actively participates in the activities being studied. In this type of observation, the researcher directly interacts with the subjects and the research environment, allowing them to gain a deeper and more holistic understanding of the social context and behaviors being observed. The main difference between participative observation and other types of observation, such as non-participative observation or structured observation, lies in the level of researcher involvement. The research design used is shown in Figure 1.

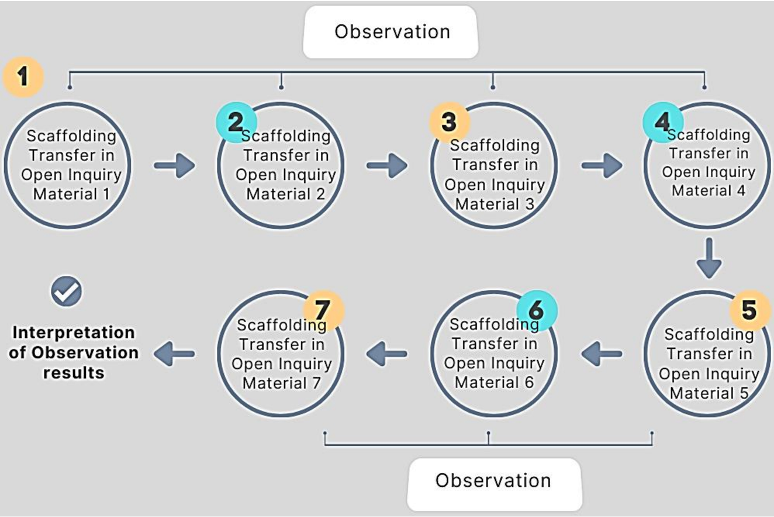


Figure 1. Participative Observation Design

The research subjects are students enrolled in the Electromagnetics course in the Physics Education Study Program at Universitas Jambi. The total number of students is 34, divided into 12 groups. Data for this research were obtained through participative observation. The instrument used was an observation sheet. The observation sheet consists of 5 dimensions, which were organized based on the inquiry learning syntax, and each dimension consists of 5 indicators. The observed dimensions include the abilities and scaffolding needed in posing questions, planning and conducting investigations, data analysis, developing explanations based on data or evidence, and communicating investigation results. Data collection was conducted by researchers directly participating in 7 learning topics (Figure 1) to observe the scaffolding transfer process in STEM-based open inquiry learning. The learning design is presented in Figure 2.

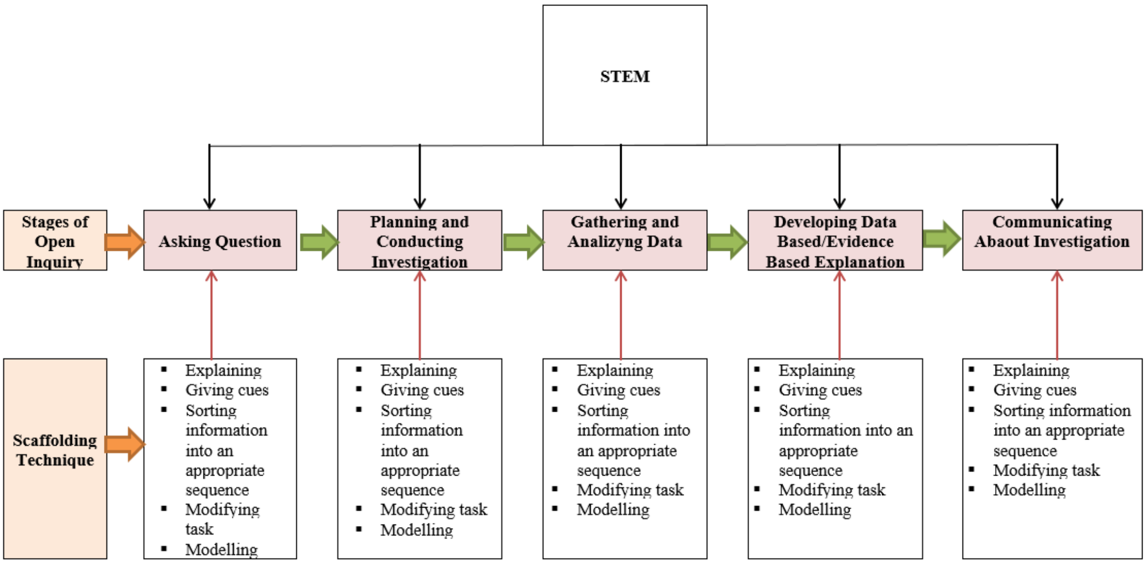


Figure 2. Scaffolding Flow in STEM-Based Open Inquiry Learning

Scaffolding transfer in STEM-based open inquiry is the process of providing temporary assistance to help students achieve deeper understanding and skill development. The data analysis technique in this study was conducted by observing and recording how students interacted with the inquiry tasks and the support provided by the teacher or other aids. The collected data were analyzed through coding to identify patterns of scaffolding use and how students gradually took over their own learning process. Coding was done deductively, i.e., based on the dimensional categories that had been arranged on the observation sheet.

The presentation of data results regarding transfer scaffolding in STEM-based open-inquiry learning is done through a combination of visualization and narrative. Data visualization in the form of bar charts is used to illustrate patterns in scaffolding used by students. These charts can show the frequency of scaffolding used during the learning process. Descriptive narrative complements this visualization by explaining the interpretation of the data, such as the relationship between the types of scaffolding used and student performance.

3. FINDINGS AND DISCUSSION

The implementation process of STEM-based open inquiry learning with scaffolding support was conducted across six topics. Each stage of open inquiry was prepared with scaffolding as assistance when students encountered difficulties. Based on the analysis of the implementation of open inquiry-based STEM design and scaffolding support, the data on the percentage of scaffolding transfer provided to students for each topic is presented in Figure 3.

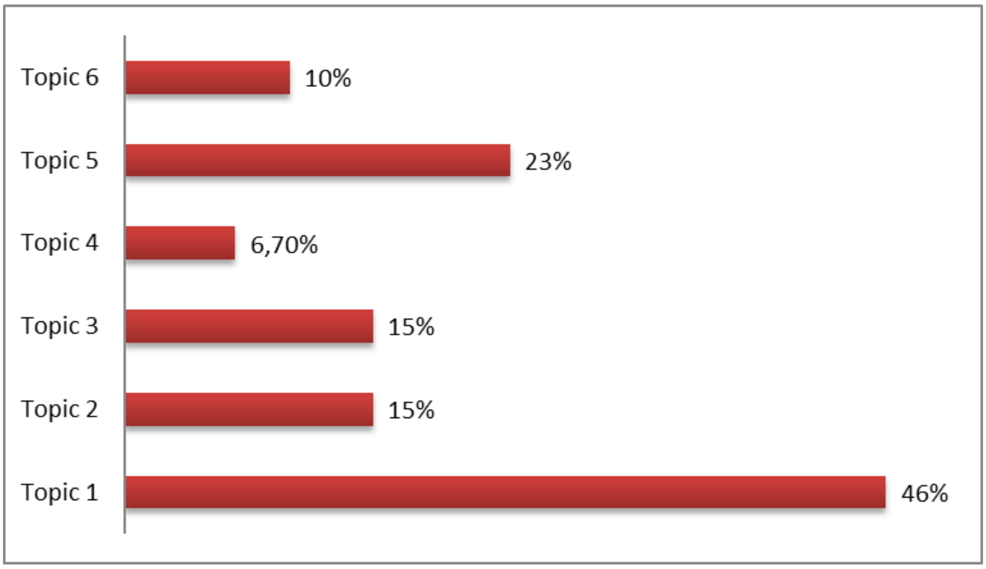
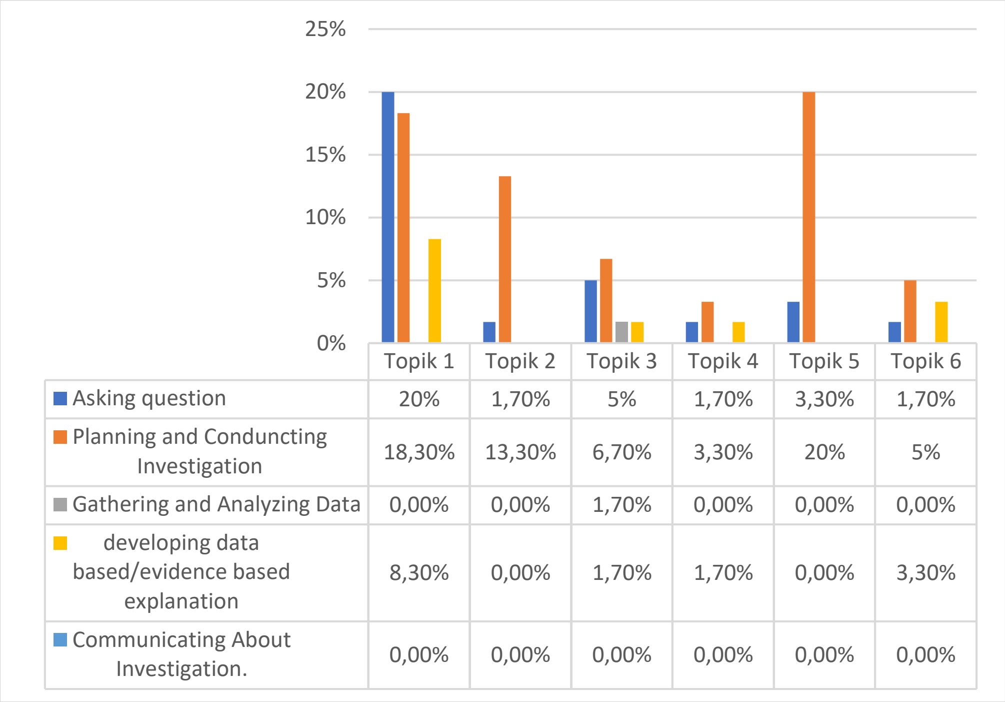


Figure 3. Percentage of Scaffolding Needs for Each Learning Topic

The results show that there are variations in the percentage of scaffolding provided in STEM-based open-inquiry learning on different topics. The data in Figure 3 shows that for Topic 1, there was a high level of support at the beginning of the learning process. Topics 2, 3 and 4 experienced a significant decrease as the students' ability to learn independently increased. However, in Topic 5, the percentage of scaffolding increased again. Finally, for Topic 6, the percentage of scaffolding slightly decreased.

The variation in the percentage of scaffolding provided, as indicated by the data above, could be due to several factors. In Topic 1, a high level of support at the beginning of the learning process was likely necessary to help students grasp the basics of complex concepts and build a strong foundation (An & Cao, 2014). As learning progressed in Topics 2, 3, and 4, the significant decrease in scaffolding reflects students' increased ability to learn independently, suggesting that they were beginning to master the skills necessary to explore and understand the material without much intervention from the instructor. However, the increase in scaffolding observed in Topic 5 may be due to the introduction of more difficult or entirely new and complex concepts (Koes-H. & Hanum, 2019). This variation reflects the changing dynamics of students' needs along with the complexity of the material and their ability to adapt to the open inquiry learning process (Tuada et al., 2020). These results are in line with previous research that supports these findings, showing that scaffolding is dynamic in that the level of support can increase again when students encounter more complex concepts (Van de Pol et al., 2012).

The distribution of scaffolding provided at each step of STEM-based open inquiry learning learning for the 12 student groups is presented in Figure 4.



	Topik 1	Topik 2	Topik 3	Topik 4	Topik 5	Topik 6
🟦 Asking question	20%	1,70%	5%	1,70%	3,30%	1,70%
🟧 Planning and Conducnting Investigation	18,30%	13,30%	6,70%	3,30%	20%	5%
⬛ Gathering and Analyzing Data	0,00%	0,00%	1,70%	0,00%	0,00%	0,00%
🟨 developing data based/evidence based explanation	8,30%	0,00%	1,70%	1,70%	0,00%	3,30%
🟦 Communicating About Investigation.	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

Figure 4. Distribution of Scaffolding Provided at Each Step of STEM-Based Open Inquiry Learning

The data in Figure 4 on the distribution of scaffolding at each step of STEM-based open-inquiry learning shows significant variation. In the "asking question" stage, Topic 1 received the highest portion of scaffolding at 20%, while Topics 2, 4, and 6 each received only 1.7%, indicating that students in these topics were more capable of independently formulating questions. Topic 3 received 5% scaffolding, and Topic 5 received 3.3%, indicating a moderate level of assistance to help students formulate relevant research questions. This finding is consistent with several studies which state that when students ask questions in open inquiry learning, they often require more scaffolding as this skill demands deep understanding and critical thinking skills that are not fully developed, especially in the early stages of learning (Nivalainen et al., 2013; Rahmat & Chanunan, 2018).

In the "planning and conducting investigation" stage, Topic 1 received 18.3% scaffolding, Topic 2 received 13.3%, and Topic 3 received 6.7%, reflecting the need for support in planning and conducting investigations. Interestingly, Topic 5 received 20% scaffolding, the highest in this stage, indicating a high complexity in planning investigations for this topic. In the "gathering and analyzing data" stage, only Topic 3 received scaffolding at 1.7%, while Topics 1, 2, 4, 5, and 6 did not receive any scaffolding, indicating that students were more adept at collecting and analyzing data independently. In the "developing data-based/evidence-based explanation" stage, Topic 1 received 8.3% scaffolding, whereas Topics 2 and 5 did not receive any scaffolding. Topics 3 and 4 each received 1.7%, and Topic 6 received 3.3%, indicating varying levels of need for support in developing data-based explanations. Finally, in the "communicating about investigation" stage, no topics received scaffolding, indicating that students were sufficiently capable of communicating their investigation results without additional assistance.

The findings in the study indicate that the percentage of scaffolding provided in STEM-based open inquiry learning varies significantly across different topics. For Topic 1, the scaffolding provided reached 46%, indicating that at the beginning of the learning process, students required more intensive support to understand basic concepts and guide their learning process. This aligns with several studies' findings that scaffolding is crucial at the early stages of learning to help students understand tasks and build a strong foundation of knowledge (La Braca & Kalman, 2021; Susilowati et al., 2019). The decrease in scaffolding percentage for Topics 2 and 3, each at 15%, suggests that over time, students begin to learn more independently with less support.

For Topic 4, the scaffolding provided was only 6.7%, indicating that students were quite independent in directing their own learning. This can be compared to the study, which found that effective scaffolding should gradually decrease as students' competencies increase (Kyza & Georgiou, 2019). However, the increase in scaffolding percentage for Topic 5 to 23% shows that the complexity of the material required additional support. This finding is supported by previous studies on scaffolding, which state that the difficulty level of tasks affects the amount of scaffolding needed by students (Eveline et al., 2019). For Topic 6, the scaffolding percentage slightly decreased to 10%, indicating that students had achieved a higher level of independence.

The distribution of scaffolding provided at each step of STEM-based open-inquiry learning also shows significant variation. In the "asking question" stage, Topic 1 received 20% scaffolding, the highest among all topics, indicating that students needed assistance in formulating relevant research questions. Meanwhile, Topics 2, 4, and 6 each received only 1.7% scaffolding, showing that students in these topics were more capable of independently formulating questions. The "planning and conducting investigation" stage shows that Topic 5 received the highest scaffolding at 20%, indicating that students needed greater support in planning and conducting investigations for more complex material. Scaffolding at this stage is essential to help students develop effective investigation strategies (Belland et al., 2013; Hsu et al., 2015; Kim et al., 2018).

In the "gathering and analyzing data" stage, only Topic 3 received scaffolding at 1.7%, indicating that students in this topic needed help in collecting and analyzing data, while students in other topics were able to do so independently. The "developing data-based/evidence-based explanation" stage shows that Topic 1 received the highest scaffolding at 8.3%, indicating that students needed assistance in developing data-based explanations. The absence of scaffolding in the "communicating about investigation" stage for all topics suggests that students were sufficiently capable of communicating their investigation results without additional support. This aligns with research showing that students' communication skills improve with experience and practice in open-inquiry learning (Belland et al., 2013, 2015; Kim et al., 2018).

4. CONCLUSION

The main objective of this research is to determine the profile of scaffolding transfer in STEM-based open inquiry learning during electromagnetic practicum. Based on the results of the study, it can be concluded that there are variations in the percentage of scaffolding provided in STEM-based open inquiry learning on different topics. This variation reflects the dynamics of changing student needs along with the complexity of the material. These results also show that scaffolding is dynamic because the level of support can increase again when students encounter new concepts or difficult concepts. In addition, the highest scaffolding in the open inquiry process occurs at the “asking questions” stage, which indicates a great need for help at the beginning of learning. In contrast, no scaffolding was provided at the stage of “communicating the results of the investigation,” which reflects students' independence.

The limitations of this research are that it only involves students from the Physics Education Program at Universitas Jambi, so the findings may not be fully generalizable to other educational contexts or levels. Additionally, the study does not explore in depth how individual variables, such as students' backgrounds or learning styles, affect the effectiveness of scaffolding. Therefore, further research that includes multiple institutions, different data collection methods, and individual variables could provide a more comprehensive understanding of scaffolding implementation in open inquiry-based STEM learning.

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