Can E-Scaffolding Influence the Shift in the Level of Scientific Reasoning in Physics Learning?

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Abstract: This study observes two groups of high school students who were given different physics learning interventions. The first group (N = 35) learning physics with e-scaffolding in modelling instructions (LPE-MI), while the second group (N = 35) learning physics with modelling instructions (LPMI). This study investigates the influence of e-scaffolding on shifts in the level of scientific reasoning (SR) of students in physics learning by using 15 items modified by Lawson's scientific reasoning test ($\alpha = 0.828$). Our data indicate that the group LPE-MI obtained a G-factor score of 0.53, while the other group achieves G = 0.37. Attention-grabbing results are seen in the shift in levels from transition to formal operations in groups of individuals. For the group LPE-MI it amounts to a significant 43% higher than the group LPMI, which is 9%. The shift in the SR level of students who learning physics with e-scaffolding was more elevated than students who only studied physics with MI, where the comparative analysis test showed an effect of 17.3%. The findings in our study prove that e-scaffolding is not only effective in helping students learn physics independently, but also able to influence students' SR level shifts better.

Keywords: E-scaffolding, Shift in Level, Scientific Reasoning, Physics Learning

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Introduction

Scientific reasoning (SR) is the core of cognitive skills in science education. From a perspective of high-level logical thinking (Kalinowski & Willoughby, 2019; Novia & Riandi, 2017; She & Liao, 2010), SR is a scientific inquiry skill that involves analyzing, hypothesizing, problem-solving, and making appropriate conclusions. Another viewpoint considers SR as a set of basic skills (Fischer et al., 2014; Nurhayati et al., 2016) in thinking and reasoning patterns (Ding et al., 2016). Meanwhile, Zafitri et al. (2019) view SR as a thinking ability that plays a crucial role in solving complex and authentic problems.

Essentially, the important goal of science education is not only to focus on students' understanding of basic concepts, but also to develop their scientific reasoning skills. Various previous studies have found that the development of SR skills has a positive impact on students' conceptual understanding (Muchoyimah et al., 2020; Nieminen et al., 2012; Sriyansyah & Saepuzaman, 2017). Sutopo & Waldrip's (2014) and Meilina et al.'s (2020) analyses found that students with high SR skills are able to understand physics concepts better. When students have high levels of SR, they will be able to optimize their potential, making them more adaptable to complex problems (Zimmerman & Klahr, 2018).

According to Piaget's theory, an individual's cognitive development progresses through stages that correspond to the development of their SR over time. The development of a child's SR is classified into three levels: concrete operational, transitional, and formal operational (Lawson et al., 2000). At the level of concrete operational reasoning (ages 6-11), students are only able to operate simple logical thinking to solve problems. At the transitional level, which is the transition stage between the concrete operational and formal operational stages, students are only able to solve some abstract problems because their cognitive knowledge schema cannot process complex logical reasoning accurately. Meanwhile, at the level of formal operational reasoning (ages over 11), students have been able to solve various abstract problems and can think using more complex logical reasoning, ultimately leading to accurate hypothetico-deductive reasoning (Stammen et al., 2018).

Despite the theory that middle and upper-level students are at the formal operational level, many researchers have shown that most upper-level students have not yet reached that level (Khoirina et al., 2018; Tajudin & Chinnappan, 2015; Widarti & Winarti, 2019). Research by Tajudin & Chinnappan (2015) showed that 9 out of 10 high school students were still at the concrete operational reasoning level, and only a small percentage of students had reached the formal operational reasoning level. Similar results were found in research on the level of SR in physics conducted by Khoirina et al. (2018)), where only 1 out of 10 students in the Indonesian high school population was able to reach the formal operational reasoning level. Meanwhile, research by Widarti & Winarti (2019) found evidence that no students had reached the formal operational reasoning level in physics learning, while 7 out of 10 students were still at the concrete operational reasoning level. These research findings suggest the need for effective learning strategies to train students' SR.

One strategy that can be used to train students' scientific reasoning (SR) skills is the application of Modelling Instruction (MI) in teaching. MI is a learning model that has syntax that is in line with the pattern of scientific reasoning. Several studies (Brewe & Sawtelle, 2018; Jumadin et al., 2017; Stammen et al., 2018; Sujarwanto et al., 2014) on modelling instruction have shown positive results on the development of students' SR in science learning. This is because the steps in MI direct students to construct scientific knowledge and reasoning in a multirepresentational manner (Jumadin et al., 2017; Lestyaningtyas et al., 2017; Ropika et al., 2019) through modeling and investigation activities. However, according to Belland et al. (2015), the low level of SR skills in students is not only caused by learning strategies but also because teachers cannot overcome all the difficulties that students experience during learning.

To overcome the difficulties experienced by students during learning in an effort to improve SR skills, there is a need for cognitive assistance that students can use independently during learning, such as the use of e-scaffolding. E-scaffolding is an online-based scaffolding that is efficient to use in supporting science learning. Various studies have mentioned that e-scaffolding can be used as cognitive assistance that can develop students' thinking processes such as reasoning, problem solving, and finding precise physics concepts (Rashid et al., 2017; Saman & Handayanto, 2017; Saputri & Wilujeng, 2017; Wu et al., 2016). An empirical study by Bell & Pape (2014)) showed that scaffolding can increase students' self-regulated learning. Scaffolding integrated with e-learning (e-scaffolding) utilizes multimedia to be adjusted to the needs of different levels of assistance and cognitive levels of students. E-scaffolding is flexible and built on constructivist principles. Through e-scaffolding, students are involved in making independent decisions (Saputri & Wilujeng, 2017), making it efficient for students who have difficulty understanding problems.

Various studies have shown that the use of scaffolding in online learning plays an important role in increasing the effectiveness of learning. Related literature shows that both teacher e-scaffolding and peer e-scaffolding have the strength to help students achieve learning goals and maximize their learning outcomes. In the subject of physics, online learning with the assistance of e-scaffolding can effectively enhance students' understanding of physics concepts (Rahayu et al., 2022; Santhalia & Sampebatu, 2020). The assistance provided by teachers in the form of e-scaffolding can facilitate students to develop their thinking skills in understanding concepts and make online learning easier. These successes form the basis for improving students' SR skills through the application of e-scaffolding in teaching methods, including the use of modelling instruction. However, the use of e-scaffolding in online learning presents several challenges, including activities for interactive questions, collaborative discussions, and the problem of technology and digital infrastructure availability that need to be considered in order to achieve success in improving students' SR skills (Nurliani et al., 2021).

The implementation of e-scaffolding in physics learning design presents both challenges and great potential for educators and researchers to develop more effective and efficient learning innovations. However, in practice, there are still few educational research studies that utilize e-scaffolding in physics learning with modeling instruction to train students' SR (scientific reasoning) abilities. In addition, most science education research is always fixated on analyzing the overall efforts to improve SR, but there is little scientific literature or empirical studies that specifically present the progress of SR skills through shifts in SR levels. Therefore, this study addresses the main problem, which is to determine whether e-scaffolding in physics learning can shift students' SR levels to a higher level than before.

Method

This research involved 70 high school students aged 16-18 years for half a semester (12 weeks) in one school in East Java, Indonesia in the academic year 2019/2020. The research method used was a quasi-experimental comparative study that observed two groups of students given different physics learning interventions. This study aimed to investigate the effect of e-scaffolding on the shift in scientific reasoning (SR) ability levels between the two groups of students in physics learning. The first group, consisting of 35 students, was the experimental group who learned physics with e-scaffolding in modeling instruction (LPE-MI), while the second group, consisting of 35 students, was the control group who learned physics with modeling instruction (LPMI).

To measure students' SR levels, we used a 15-item modified Lawson scientific reasoning test that has been tested for validity with a reliability of $\alpha = 0.828$. The questions in the test instrument refer to 6 indicators of SR patterns: conservation reasoning, proportional reasoning, probabilistic reasoning, control of variables, correlational reasoning, and deductive hypothesis reasoning. The total score obtained from all indicators is then classified based on the SR level criteria (see table 1).

Table 1. Scientific Reasoning Level Classification

Total score	Level
0% - 33%	Concrete operations
34% - 67%	Transition
68% - 100%	Formal Operations

Adaptation of Babakr et al. (2019)

In this study, the measurement of improvement in SR ability on the post-test in relation to the pretest was evaluated using the G-normalized gain parameter. Meanwhile, the data analysis for the comparison test in this study used the paired t-test with the condition of sig. < 0.05. This test was used to determine the statistical difference in the SR results before and after the intervention, so that we could evaluate how the intervention difference could affect the migration of students' SR levels.

Results

The results indicated that there was no statistically significant difference in the pre-test SR results between the two observed groups (p > .05). The analysis showed that most students in both the LPE-MI and LPMI groups were still at the concrete and transitional reasoning levels. Even in the LPMI group, there were no students who had reached the formal operational level before the course. The comparison between the pre-test and post-test results in SR level between the two groups is presented in table 2. Our data showed that both groups showed improvement, but the students in the experimental group (LPE-MI) were almost three times more successful in reaching the formal operational level compared to the control group (LPMI).

Table 2. Comparison of pretest and posttest scientific reasoning results between LPE-MI and LPMI groups

		Scientific Reasoning level classification (%)		
		Concrete	Transisi	Formal
LPE-MI Group (N=35)	Pretest	37	60	3
	Posttest	0	37	63
	Shift	-37[a]	-23[b]	60[a]
LPMI Group (N=35)	Pretest	43	57	0
	Posttest	0	77	23
	Shift	-43[a]	20[b]	23[b]

[a] Significant shifts, *p<.05*
[b] Non-significant shifts, *p>.05*

For the LPE-MI group, the pretest SR score prior to the course indicated that 37% of students were in the concrete operational thinking level, 60% were in the transitional thinking level, and 3% were in the formal operational thinking level. After the intervention, 0% of students were in the concrete operational thinking level, 37% were in the transitional thinking level, and 63% were in the formal operational thinking level. These results indicate that the SR level of the experimental group increased significantly by 60% in the formal operational level after participating in physics learning with e-scaffolding in modelling instruction.

On the other hand, the pretest SR score for the LPMI group before the intervention indicated that 43% of students were in the concrete operational thinking level, 57% were in the transitional thinking level, and none were in the formal operational thinking level. Whereas, after the course, the posttest SR score for the LPMI group showed that none of the students were in the concrete operational thinking level, 77% of students were in the transitional thinking level, and 23% of students had entered the formal operational thinking level. These results indicate that the LPMI group experienced a substantial increase in the formal operational level but not a significant one.

Overall, both the LPE-MI and LPMI groups experienced an improvement in SR ability in the moderate category as indicated by the normalized gain factor (G-factor). The LPE-MI group obtained a G-factor score of 0.53, while the LPMI group obtained a G-factor score of 0.37 (see figure 1).

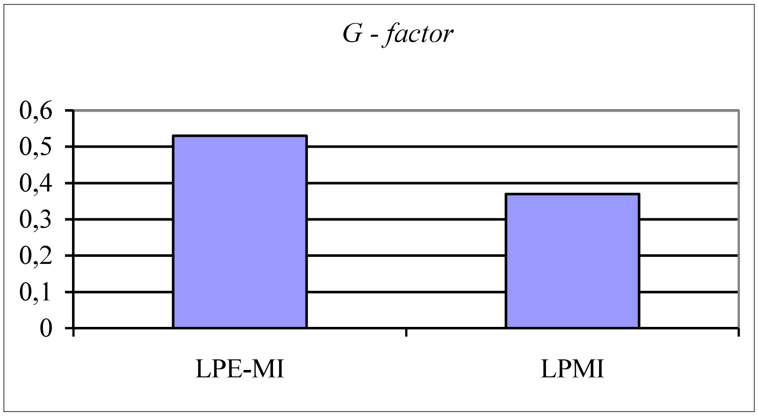

Figure 1. *G-factor* for LPE-MI and LPMI

The improvement of SR ability in both groups as observed in the data analysis indicates a shift in the level of SR. Table 3 shows the results of the analysis of migration between levels of scientific reasoning among students in both physics learning groups.

Table 3. Comparison of Migration of Scientific Reasoning Levels of Students in LPE-MI and LPMI groups

LPE-MI					LPMI				
Pretest		Posttest		(%)	Pretest		Posttest		(%)
Concrete	13	Concrete	0	0	Concrete	15	Concrete	0	0
		Transisional	7	20[a]			Transisional	10	28[a]
		Formal	6	17[a]			Formal	5	14[a]
Transisional	21	Concrete	0	0	Transisional	20	Concrete	0	0
		Transisional	6	17			Transisional	17	49
		Formal	15	43[a]			Formal	3	9[b]
Formal	1	Concrete	0	0	Formal	0	Concrete	0	0
		Transisional	0	0			Transisional	0	0
		Formal	1	3			Formal	0	0

[a] Significant shifts, *p<.05*
[b] Non-significant shifts, *p>.05*

In the LPE-MI group, 20% of students shifted from the concrete to transitional level, 17% of students shifted from the concrete to formal operational level, and 17% of students remained in the transitional level. Meanwhile, in the LPMI group, 28% of students shifted from the concrete to transitional level, 14% of students shifted from the concrete to formal operational level, and 49% remained in the transitional level. Special attention was given to observing the migration of individuals from the transitional to formal operational level in each group. In the LPE-MI group, 43% of students experienced a shift from the transitional to formal operational level, which was much higher than the LPMI group, which only reached 9%. Additionally, a comparative analysis between the two groups also showed that the integration of e-scaffolding effectively influenced the shift in SR level by 17.3%, where the SR level of students who learned physics with E-MI was higher than those who only learned physics with MI.

Discussion

This study investigates the effectiveness of e-scaffolding in modeling instruction to enhance high school students' scientific reasoning (SR). This topic is considered the most important aspect of Modeling Instruction (MI). The study employs an analysis of students' shift in reasoning levels from concrete-transitional-formal in classes using and not using e-scaffolding in modeling instruction. Our research findings confirm Omarchevska et al.'s (2022) study showing that the assistance provided did not affect the modeling learning environment. One possible explanation is that students did not effectively use the provided scaffolding. Another possibility is that the e-scaffolding provided may elicit different responses depending on students' prior knowledge (van Riesen et al., 2018, 2022). Although we did not directly measure prior knowledge in this study, we measured students' scientific reasoning before the intervention. Referring to the strong correlation between knowledge and scientific reasoning (Muchoyimah et al., 2020; Mustika et al., 2019; Purwanti et al., 2016). it is possible that students need sufficient prior knowledge to use scaffolding effectively in their learning or that students with high prior knowledge experience a reverse expertise effect that inhibits their scientific reasoning development (Richter & Scheiter, 2019).

In the scientific reasoning research community, modeling is one of the reasoning styles proposed by (Kind & Osborne, 2017). Therefore, modeling instruction is an effective strategy to enhance students' scientific reasoning skills (Stammen et al., 2018). However, it can be a challenging task for students as it requires strong conceptual understanding and high-level abstract thinking. Consistent with the results of this study, students do not necessarily maximize their learning through modeling instruction. This may be due to some obstacles students face in acquiring knowledge and modeling because of increased cognitive load (Sweller, 1988), resulting in a minimal shift towards formal operational reasoning in LPMI compared to the LPE-MI class. These results confirm Stammen et al. (2018) research on prospective teachers.

While this study highlights the shift in scientific reasoning skills among a group of high school students, further exploration of moderation variables that influence SR in various fields and areas is needed. This study is limited to the participants and region involved in this research. In addition, in terms of educational implications, we suggest that educators provide e-scaffolding that explicitly trains SR to guide students to the formal operational level.

Conclusion

Based on the results and discussion, it can be inferred that learning physics in both groups (LPMI and LPE-MI) can increase students' scientific reasoning. However, it was found that the increase in the SR level of students who learning physics with e-scaffolding in modeling instructions (LPE-MI) was higher compared to the group who only learning physics with modeling instructions (LPMI). Moreover, a significantly higher number of students in the LPE-MI group progressed from the transitional level to formal operations, as opposed to the LPMI group, which only reaches 9%. Overall, the findings in our study prove that e-scaffolding is not only effective in helping students learn physics independently, but also able to influence students' SR level shifts better.

Recommendations

The purpose of this study is to provide some recommendations that may be beneficial for educators and researchers in the future. Firstly, it is important to create a more comprehensive evaluation of scientific skills in physics learning, including scientific reasoning standards and self-efficacy, to minimize bias related to content-based scientific reasoning. Secondly, we encourage future researchers to expand on this study by investigating the impact of incorporating E-scaffolding in learning Physics with Modelling Learning (LPE-MI) on the shift in levels of other scientific skills to provide more diverse learning insights.

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