Enhancing the Reasoning Performance of STEM Students in Modern Physics Courses Using Virtual Simulation in the LMS Platform

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Abstract—The difficulty of tutors in all types of learning (face-to-face and online) is when they teach abstract concepts in modern physics courses, especially to improve students' reasoning skills. We see an opportunity that advances in digital technology can help overcome this problem. This study aims to improve the reasoning performance of STEM students in modern physics courses using virtual simulation integrated with the LMS platform. Experimental design was prepared with one control group (face-to-face learning with expository method). The sample was 54 STEM students at the University of Mataram which was divided into the experimental group (n = 27) and the control group (n = 27). Reasoning skills were measured using an essay test instrument, and the results were analyzed descriptively (analysis of increasing reasoning skills scores) and statistically (analysis of differences in reasoning skills scores between sample groups). The results of this study have clearly shown that the reasoning performance of STEM students in modern physics courses can be improved by learning using virtual simulation on the LMS platform. Descriptive and statistical analysis of the reasoning performance of STEM students shows the advantages of learning using virtual simulation when compared to face-to-face learning that relies on expository methods. We recommend using virtual simulation on the LMS platform to teach abstract concepts that are not limited to modern physics but in science learning in general.

Keywords—reasoning skills, virtual simulation, modern physics courses

1 Introduction

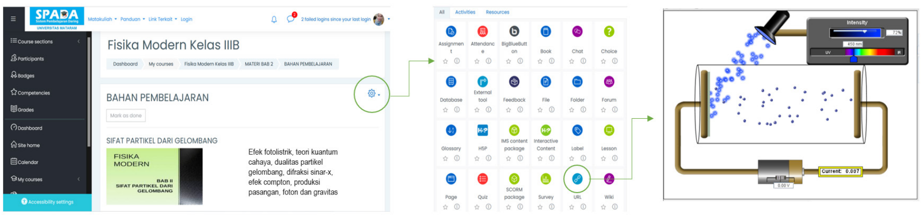
Technology has penetrated all areas of human life, including in education. The use of technology as a form of aggressiveness in all types of activities in the 21st century. Mobile tablets and smartphones provide continuous access for users anywhere and anytime. Accessibility has an impact on the ease of finding information efficiently and has an impact on open social access with other people [1]. Embedding the transformation of learning using technology is a necessity, especially now that its use is increasingly massive in the midst of the Covid-19 pandemic, where technology is no longer a secondary learning tool but has become a primary need in conducting learning materials to students at all levels of education, including higher education.

Technology can provide the right medium for teachers to nurture higher-order thinking in students, a key element of 21st century skills [2], through carefully structured activities [3], [4]. However, most of the time the use of technology in education is used as a source of information rather than as a process-based means to construct knowledge [5]. Therefore, to make a difference to the widespread use of technology, technology must be used as a pedagogical tool for learning and teaching [6], and the pedagogical value of technology is reflected in the level of student involvement and the nature of their participation in learning [7].

Within the framework of STEM education, the fulfillment of new styles of learning is increasingly relevant as technology develops rapidly and this leads to virtual systems [8]. The conduction of learning that utilizes it is not a temporary phenomenon that will last a short time, but the current and future educational formats are likely to continue to utilize technology [9]. One of the uses of technology in learning is a virtual learning system (e-learning). In the design of classroom learning, education providers are encouraged and asked to prepare e-learning to balance the interest in this technology [10]. A long before the Covid-19 Pandemic, many institutional organizations around the world used online systems as an alternative teaching method [11]. In line with the development of online learning technology, a pedagogically effective instructional design is needed to facilitate the achievement of learning objectives, better learning outcomes performance, and create an attractive learning environment so that students do not lose their interest in learning [12].

The interaction and involvement of STEM students in learning is still a problem [13], especially in relation to practicing their reasoning skills [14]. This reasoning ability is an important concern because it is a predictor of student achievement in the STEM field [15]. Reasoning in a more familiar context is called critical thinking [16], [17], this is identified with the attribution of specific abilities such as analysis, inference, evaluation, and decision making [18]–[22]. Acquiring this attribution of critical thinking or reasoning is very important for students [20], it's just that the arguments of previous studies [23] show that effective learning designs to train them are still not well established, especially in supporting STEM student interactivity and engagement. Referring to our experience of teaching physics courses for more than 10 years, there are difficulties in how to teach physics on materials with a high level of abstraction such as modern physics courses. This has an impact on the low reasoning of students, coupled with the interest and motivation to learn students tend to fall. However, we are optimistic about the current massive technological developments that can mediate the teaching of modern physics in more interactive ways and can visualize abstract concepts in physics. Previous studies have recommended the use of virtual simulations in teaching science concepts, and it has resulted in better concept mastery, a better preference for scientific theory, and an increase in students' thinking skills [24].

Teaching with an e-learning system brings students to a virtual environment, visualization of material in many aspects of teaching is found in many formats such as augmented reality, gamification, virtual and remote laboratory, virtual reality, interactive video, and virtual simulation [24], [25]. Focus in the current study is on virtual simulations, where the results of a study by Hassan and colleagues [26] show that student acceptance is very good in its application in the classroom, and has a positive impact on three areas of student learning (knowledge, skills, and attitudes), and conclusively impact on students' better academic performance [27]. The advantages are clear, virtual simulation helps overcome physical and mental limitations in reaching abstract concepts, and helps overcome other problems in learning related to accessibility [28]. Virtual simulations have now developed, in which experimental spaces and designs are prepared students can manipulate experimental parameters according to their needs [29]. In the e-learning system at the university, it is integrated with the Learning Management System (LMS) at the university and its use depends on access permission from the designer (some can be accessed freely or otherwise), they are lecturers as full controllers of the learning system through the LMS. In relation to the current study, we integrated virtual simulation with LMS in modern physics courses to improve the reasoning abilities of STEM students. The learning design in this study is presented in Figure 1.



(a) (b) (c)

Fig. 1. Learning design in modern physics courses using virtual simulation in the LMS platform

The literature on the use of technology in education and learning is mostly directed at cognitive domains, such as knowledge; technology, content, pedagogical, content-pedagogical, technological content, pedagogical-technology, and technological knowledge [1]. In addition, another study highlights the attitude aspect in its use [30]. However, -in our best knowledgement-, the use of technology (virtual simulation) in modern physics lectures to build reasoning abilities of STEM students has not been studied adequately. For the distance learning system, the university has built a learning system infrastructure within the LMS platform.

2 Research methods

2.1 Research design

This study is an experimental study with the randomized pretest-posttest control design [31]. Through a randomization scheme, two sample groups have been determined. They were given treatment as experimental (E) and control (C) groups. The experimental group was given learning treatment using virtual simulation in the LMS (e-learning) platform, while the control group with face-to-face learning used the expository method. Before treatment, both sample groups were observed for their reasoning abilities as pretest (O_1) and posttest (O_2). In simple terms, the research design is as follows.

Experimental group	R	O_1	E	O_2
Control group	R	O_1	C	O_2

The study was carried out on both groups of samples on the same material in modern physics courses, namely the photoelectric effect, quantum theory of light, wave particle duality, x-ray diffraction, Compton effect, pair production, photons and gravity. This material is taught to STEM students in four meetings.

2.2 Research sample

The sample was 54 STEM students at the University of Mataram which was divided into the experimental group (n = 27) and the control group (n = 27). Demographics of the sample is presented in Table 1.

Table 1. The Sample demographics

Characteristics		Exp. group, n = 27		Cont. group, n = 27	
		Quantity	***%***	***Quantity***	***%***
Gender	Female	23	85%	17	63
	Male	4	15%	10	37
Age (year)	< 18	1	4%	0	0
	18 – 19	24	89%	23	85
	> 19	2	7%	4	15

2.3 Research instruments and analysis

The data of reasoning skill (RS) of STEM students according to indicators; reasoning-analysis (RA), reasoning-inference (RI), reasoning-evaluation (RE), and reasoning-decision making (RD) were collected using an essay test instrument. Each indicator consists of two items so that the number of reasoning ability test items is 8 questions. The highest score assigned by each item as the maximum reasoning ability is +4 (descriptor: the answer was correct, and a strong argument supported each reasoning indicator with facts, concepts, and laws), and the lowest is 0 (no answer was provided). Based on this scoring criterion, it is then converted into an equation interval (Prayogi et al., 2018), and the interval category of reasoning ability is summarized in Table 2. Reasoning skill is measured based on parameters of indicator (RSi) and individual (RSs).

Table 2. Criteria for reasoning skills based on parameters of RSi and RSs

Reasoning skills criteria	Score intervals of RSi	Score intervals of RSs
Very good	RSi > 3.21	RSs > 25.60
Good	2.40 < RSi ≤ 3.21	19.20 < RSs ≤ 25.60
Enough	1.60 < RSi ≤ 2.40	12.80 < RSs ≤ 19.20
Less	0.80 < RSi ≤ 1.60	6.41 < RSs ≤ 12.80
Poor	RSi ≤ 0.80	RSs ≤ 6.41

Data analysis of reasoning skills descriptively refers to the criteria in Table 2, and the increase in the score of reasoning skills (n-gain) refers to Hake's formulation [32]. Furthermore, statistical analysis (difference test between sample groups) was carried out to determine the difference in the increase in reasoning skill scores in the two samples ($p < 0.05$). This was preceded by a normality test ($p > 0.05$) using the Shapiro Wilk test (because the sample group members were < 50). Statistical analysis using SPSS 25.0 tool.

3 Results and discussion

The summary of the results of the descriptive analysis of reasoning skills in STEM students is presented in Table 3, this refers to the reasoning skill criteria of each treatment group based on the parameters of the four indicators (RSi).

Table 3. The results of the measurement of each reasoning skill indicator (RSi)

Group	N	Score	Reasoning skill indicator (RSi)				RSi average
			RA	***RI***	***RE***	***RD***	
Experimental	27	Pretest	1.11	1.02	1.13	0.96	1.06
		Posttest	3.04	3.19	3.24	3.20	3.17
		N-gain	0.67	0.73	0.74	0.74	0.72
Control	27	Pretest	1.11	1.04	1.11	1.15	1.10
		Posttest	1.37	1.43	1.39	1.31	1.38
		N-gain	0.09	0.13	0.10	0.06	0.09

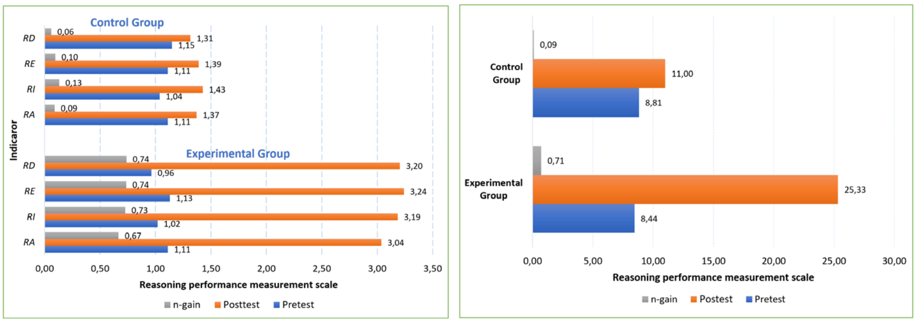
The results in Table 3 show an increase in the pretest to posttest scores according to the RSi criteria for both treatment groups. For the experimental group, the highest increase was found in the RE and RD indicators followed by RI and RA indicators, the average increase in the RSi score for the experimental class was 0.72 with high criteria.

An increase in RSi on the low criteria was found in the control group with an n-gain of 0.09. Furthermore, the performance of the reasoning skills of each treatment group based on the RSs parameter is summarized in Table 4.

Table 4. The results of the measurement of reasoning skills based on the RSs parameter

Group	N	Reasoning skills score and criteria				n-gain	Category
		O_1	*Category*	O_2	*Category*		
Experimental	27	8.44	Kurang	25.33	Baik	0.72	High
Control	27	8.81	Kurang	11.00	Kurang	0.09	Low

The summary of the RSs results in Table 4 indicates the good performance of reasoning skills of STEM students in the experimental group, on the contrary, the RSs control group is categorized as poor in pre and posttest. Visualization of the results of the reasoning skills of STEM students based on the RSi and RSs parameters is presented in Figure 2.



(a) (b)

Fig. 2. Reasoning skills of STEM students: a) based on the RSi parameter, and b) based on the RSs parameter

The results in Figure 2 clarify the differences in the performance of STEM students' reasoning skills in the two treatment groups. Based on the RSi parameter in the pretest-posttest, students' reasoning skills increased from 'less' to 'good' and this was different from that found in the control group they remained in the 'less' category. Furthermore, the difference in the increase in reasoning skill scores between the two groups was tested. statistically, this is based on the assumption of normality in both groups. The summary of the results of the normality test is presented in Table 5.

Table 5. Normality test results, $p > 0.05$

Group	Shapiro-Wilk			Data normality
	Statistic	*Df*	*Sig.*	
Experimental	0.947	27	0.184	Normally distributed
Control	0.888	27	0.007	Not normally distributed

One of the two groups of data to be compared is not normally distributed, therefore the difference test of the two data groups uses a non-parametric test (Mann Whitney test). The results are presented in Table 6.

Table 6. Mann Whitney test results, $p < 0.05$

Group	n	Mean Rank	Sum of Ranks	Mann-Whitney	Sig. (2-tailed)
Experimental	27	41.00	1107.00	0.000	0.000
Control	27	14.00	378.00		
Total	54				

The results of the Mann-Whitney test showed sig. <p (0.05), it means that there is a significant difference in the reasoning skills of STEM students between the two treatment groups. Confirming the results of this analysis, it has been explicitly proven that the reasoning skills of STEM students who are treated with learning using virtual simulations in an LMS (e-learning) platform are better than face-to-face learning using the expository method. The results of this study are in accordance with what was found in previous studies, that virtual simulations can improve students' thinking skills [24]. In another study it was found that computer-based simulation had a positive impact on students' reasoning abilities [33].

Virtual simulations allow learners to build visual representations during the learning process, and this has an impact on their critical reasoning [34]. The findings of this study have confirmed that in addition to supporting learning interactivity, virtual simulations have an impact on improving the reasoning performance of STEM students so that it can be used as a cognitive tool in a wider learning context. Visualization of abstract concepts or theories can motivate STEM students in learning and their higher order thinking skills can develop [35]. Although in the context of the current study we did not explicitly observe the learning motivation of STEM students with the application of this virtual simulation, in fact the acceptance or response of STEM students was very good which was marked by the interactivity that was built in learning. It was also found in a previous study [26] that student acceptance was very good in the application of virtual simulations in the classroom, and had a positive impact on the realm of learning in terms of knowledge, skills, and attitudes.

This study has met expectations on the fulfillment of student accessibility in understanding modern physics concepts that are not limited to space and time. When compared to face-to-face learning that relies on expository methods, the reasoning performance of STEM students is superior to learning that uses virtual simulation. The advantages are clear, virtual simulation helps overcome physical and mental limitations in reaching abstract concepts, and helps overcome other problems in learning related to accessibility [28]. Finally, for the continuous learning process we recommend the use of virtual simulation in particular to teach abstract concepts in science, and of course this requires professionalism and serious efforts from stakeholders to achieve better learning goals and outcomes.

4 Conclusion

The results of this study have clearly shown that the reasoning performance of STEM students in modern physics courses can be improved by learning using virtual simulation on the LMS platform. Descriptive and statistical analysis of the reasoning performance of STEM students shows the advantages of learning using virtual simulation when compared to face-to-face learning that relies on expository methods. We recommend using virtual simulation on the LMS platform to teach abstract concepts that are not limited to modern physics but in science learning broadly.

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