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Nurturing Prospective STEM Teachers' Critical Thinking Skill through Virtual Simulation-Assisted Remote Inquiry in Fourier Transform Courses

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Abstract

Alignment of inquiry learning has embarked on remote inquiry as a replacement for face-to-face inquiry. On the other hand, the current technological developments bring opportunities to use it as a learning resource to support critical thinking. The current study explores the impact of virtual simulation-assisted remote inquiry in Fourier transform courses on prospective STEM teachers' (PST) critical thinking (CT) skills. The experimental design employed a randomized pretest-posttest control group was employed. Two groups of samples were randomized: the experimental group, n = 30, and the control group, n = 30. The treatment of learning was different in each group. The experimental group was conducted by virtual simulation-assisted remote inquiry, while the control group was conducted by online learning without inquiry and simulation. The measured CT skills aspects included analytical, inference, evaluation, and decision-making measured by an essay test instrument. The results were then analyzed descriptively and statistically. The results confirm that the virtual simulation-assisted remote inquiry significantly improved PST CT in Fourier transform courses. The virtual simulation-assisted remote inquiry learning was better than courses with online learning without inquiry and simulation. The virtual simulation-assisted remote inquiry provided conceptual formation and application of concepts. It strengthened the opportunities for the PSTs to train their CT skills.

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INTRODUCTION

Thinking, contemplating, and learning new information are prominent features of human. Yet, reasoning is the central axis of all these activities (Byrnes, 2012). Educational and learning systems developments in the last few decades have been directed at how students can think critically (Hasemi, 2011). As pioneers in education, teachers carry out mandates to train critical thinking (CT) skills (Fuad et al., 2017). Problems in education, including STEM education, are poor learning processes or methods of conditioning students to think critically (Pursitasari et al., 2020). It eventually results in poor quality of general education.

STEM teachers' -as one of main stakeholder- are often attributed as the leading cause of the poor quality of education (Rubini et al., 2016; Wahidin & Romli, 2020). Therefore, to improve education quality, it is necessary to produce STEM teachers' who can train students' CT skills. Early improvements can be made to prospective STEM teachers, in which the CT skill should be instilled since they are in college. As such, when they become STEM teachers, they can provide such training to their students (Lam et al., 2003). In addition, educational institutions have to take responsibility for facilitating the training of CT skills to prospective teachers (Innabi & Sheikh, 2007).

Being critical in thinking refers to a person's ability to solve problems based on reflective analysis and evaluation of information/knowledge (Ennis, 2011). More philosophically, CT is the ability to make scientific decisions based on processing the information rationally and reflectively (Ennis, 2011; Hassard, 2005) through systematic analysis, making inferences based on deductive or inductive reasoning, and appropriate evaluation (E. R. Lai, 2011). CT is thus essential for academic studies (Abrami et al., 2008). CT characteristics that require a person to demonstrate skills such as interpretation, analysis, inference, explanation, self-regulation (Facione, 2020), evaluation, and decision making (Prayogi et al., 2019; Verawati et al., 2021; Wahyudi et al., 2019) were relevant to the 21st-century learning demands. Success in undergraduate education is strongly associated with competence in CT (Halpern, 2014). Therefore, encouraging the development of students' CT is considered an essential outcome of higher education (Tiruneh et al., 2017). Thus, it is vital to implement and evaluate instructional teaching that can be used to promote CT (Guo & Wang, 2021).

The most popular teaching model for practicing CT skills is inquiry. Inquiry learning aims to enable learners to think (Arends, 2012). The inquiry process is inseparable from CT. As Llewellyn (2001) stated, developing the thinking process in inquiry-based teaching can train CT skills. Inquiry-based learning can also improve students' CT skills (Thaiposri & Wannapiroon, 2015). Inquiry learning mainly aims to enhance CT, such as the use of logical thinking, analysis of occurrence and phenomenon, correctly identifying assumptions, critical analysis to secondary sources, analysis of an argument by referring to the most current scientific knowledge, considering the evidence, and checking logic (Bailin, 2002).

The challenge faced in CT training for STEM students is the complexity of the content of the material that requires abstract thinking, for example, found in the Fourier transform course. It is challenging to train CT in Fourier transform courses. It is recognized by other studies that the Fourier transform material is understood as a difficult one (Kohaupt, 2015), even though the material for Fourier transform is a unifying topic in the field of STEM study (Shoenthal, 2014). It is recommended to use virtual simulation to teach the concept of Fourier transform (Wietecha et al., 2021). In addition, the biggest challenge for CT training is the limitation of face-to-face learning caused by the Covid-19 pandemic crisis (Silva et al., 2022). It is necessary to realign learning strategies previously carried out face-to-face to distance learning (remote learning) (Sangster et al., 2020). In the end, reforms were also carried out on traditional inquiry teaching to allow remote or online inquiry by utilizing information and communication technology (ICT) resources (Novitra et al., 2021). On the one hand, this can be an opportunity to develop digital literacy skills. According to Hanson's framework, a traditional inquiry is an orientation, exploration, conceptual formation, application, and closure (Hanson, 2005). In the current study, the learning carried out by remote inquiry within the LMS framework is presented in Figure 1.

Remote inquiry is easier to be accessed, including using the use of popular and user-friendly mobile technology. Remote inquiry by utilizing ICT resources integrated with the university's e-learning platform provides easy access to students in all modes of mobile learning. This learning mode belongs to digital and mobile learning (Prahani et al., 2022). ICT in remote inquiry learning was proven to enhance students' higher-order thinking skills (Novitra et al., 2021). Variety of virtual simulations can be used as learning resources. One of the virtual simulations that is used as a learning resource is the PhET virtual simulation (Chinaka, 2021). The virtual PhET simulation can be integrated with remote inquiry learning, especially for CT skill training.

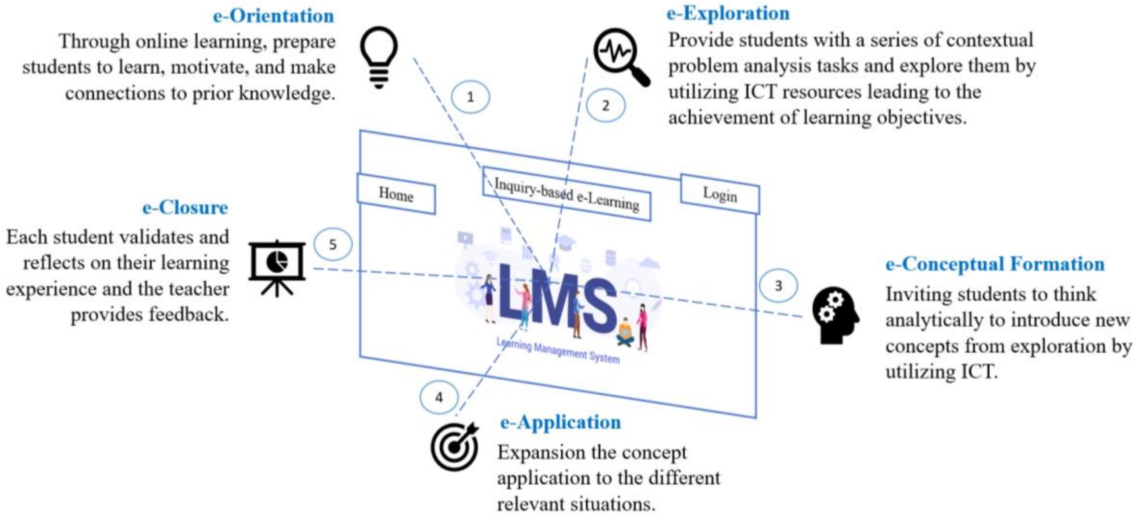

Figure 1. Remote inquiry learning within the LMS framework

The current study aims to explore the impact of virtual simulation-assisted remote inquiry in Fourier transform courses on prospective STEM teachers' (PST') CT skills. This study is very important especially in remote-inquiry learning assisted by virtual simulations as a guide or way to nurture CT skills of PSTs.

METHOD

Research Background

The randomized pretest-posttest control group was employed as the experimental design in this study summarized in Table 1. Two groups of samples were randomized from the study population of PSTs at Mandalika University of Education. They were the experimental group (E), n = 30, and control (C), n = 30. The treatments of learning was different in each group. The experimental group was exposed to virtual simulation-assisted remote inquiry. The control group was exposed to online learning without inquiry and simulation.

Table 1. Experimental design

Group	Obs.-1	Treatment	Obs.-2
Experimental (E)	Pretest	Virtual simulation-assisted remote inquiry	Posttest
Control (C)	Pretest	Online learning without inquiry and simulation	Posttest

Initial observations of CT skills were measured in both groups (pretest, O_1), then learning in each group according to the treatment that had been pre-determined, and final observations of CT skills in both groups (posttest, O_2). The learning was carried out on the Fourier transform course to both sample groups. The experimental group included the virtual simulation-assisted remote inquiry. Learning was carried out in five meetings, each meeting was approximately 90 minutes. An example of a virtual simulation taught through remote inquiry is shown in Figure 2.

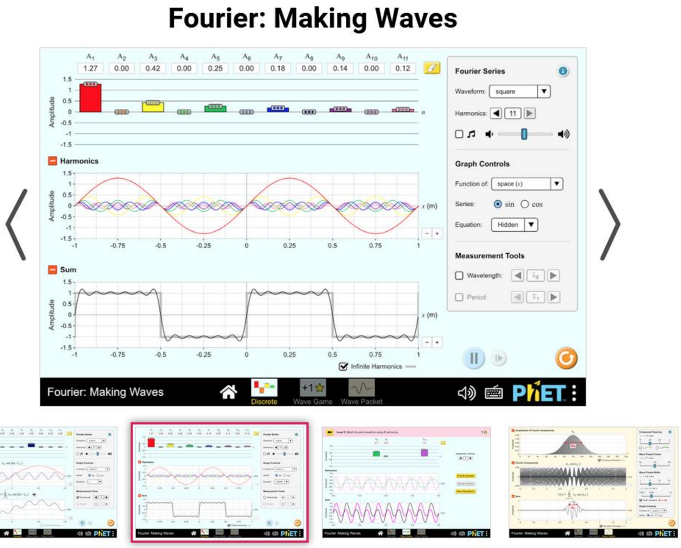

Figure 2. Virtual simulation used as learning content for the the experimental group

Research Sample

A total of 60 prospective STEM teachers from Mandalika University of Education were used as research samples. They were evenly divided into experimental (n=30) and control (n=30) groups. The sample demographics are summarized in Table 2. The ethical and legal aspects of the research have been approved by the ethics committee of the Faculty of Applied Science and Engineering, Mandalika University of Education.

Table 2. Demographic of the samples

Group	Sample characteristics, n (%)				
	Gender		Age (year)		
	Male	Female	< 18	18 to 19	> 19
Experimental, n = 30	16 (53%)	14 (47%)	0 (0%)	25 (83%)	5 (17%)
Control, n = 30	15 (50%)	15 (50%)	1 (3%)	26 (87%)	3 (10%)

Research Instruments and Analysis

An essay test of eight questions was used as an instrument to collect the CT skill data. Before being used, the test instrument was validated. The instrument was declared valid by three ecpert validators. The measured aspects of CT skills were analysis, inference, evaluation, and decision making. Graded scoring scales were employed ranged from 0 (lowest score) to +4 (highest score) on each test item. Finally, the maximum CT skill score that an individual can achieve cumulatively was +32. Categorization of CT skills (CTs) is presented in Table 3.

Table 3. Categorization of critical thinking skills

Score intervals of CT skill	Category
CTs > 25.60	Very critically
19.20 < CTs ≤ 25.60	Critically

Score intervals of CT skill	Category
12.80 < CTs ≤ 19.20	Sufficient
6.41 < CTs ≤ 12.80	Less critically
CTs ≤ 6.41	Not critically

Each CT skill data was analyzed descriptively, the CT skill performance refers to the score interval in Table 3, and the increase refers to the n-gain formulation from Hake (Hake, 1999). Based on the n-gain parameter, the improvement of CT skill between sample groups was statistically analyzed. This was preceded by a normality test (employing the Shapiro Wilk test, $p > .05$). If it met the assumption of normality, statistical analysis used independent sample t-test ($p < .05$), with the formulation of the hypothesis was H_0 (no significant difference in the improvement in CT skills between the experimental and control groups), and H_a (there was a significant difference in improvement in CT skills between the experimental and control groups). Statistical analysis was done using SPSS 25.0 tool.

RESULTS AND DISCUSSION

Based on the categorization in Table 3, the frequency distribution based on the results of the CT skill analysis is presented in Table 4. It should be noted that all members of the sample groups were involved in the pretest and posttest. The results of the CT skill descriptive analysis (pretest-posttest score and category) are presented in Table 5.

Table 4. Frequency distribution of CT skill by interval category

Category	Interval	Exp. Group, n (%)		Cont. group, n (%)	
		Pretest	Posttest	Pretest	Posttest
Very critically	CTs > 25.60	0 (0.0)	23 (76.7)	0 (0.0)	0 (0.0)
Critically	19.20 < CTs ≤ 25.60	0 (0.0)	7 (23.3)	0 (0.0)	0 (0.0)
Sufficient	12.80 < CTs ≤ 19.20	6 (20.0)	0 (0.0)	5 (16.7)	27 (90.0)
Less critically	6.41 < CTs ≤ 12.80	23 (76.7)	0 (0.0)	25 (83.3)	3 (10.0)
Not critically	CTs ≤ 6.41	1 (3.3)	0 (0.0)	0 (0.0)	0 (0.0)
Amount		30 (100)	30 (100)	30 (100)	30 (100)

The pretest results of the experimental group indicate that 23 PSTs (76.7%) were categorized as 'less critically,' the rest were categorized as 'sufficient' and 'not critically.' The results of the control group pretest indicated that 25 PSTs (83.3%) were categorized as 'less critically,' and the rest were categorized into 'sufficient.' The pretest results in both sample groups showed no scores from the PSTs in the 'critically' and 'very critically' categories. After learning treatment in each sample group resulted in various changes in their CT skills. The posttest experimental group was distributed in the 'critically' (7 PSTs, 23.3%) and 'very critically' (23 PSTs, 76.7%), while in the control group they were distributed into the 'sufficient' category (27 PSTs, 90%) and the rest were 'less critically.'

Table 5. Measurement results from CT skill

Group	CT skill (pretest-posttest score)				n-gain	Category
	Pretest	Category	posttest	Category		
Experimental, n = 30	10.73	Less critically	26.30	Very critically	0.73	High
Control, n = 30	11.00	Less critically	13.93	Sufficient	0.14	Low

The data in Table 5 show the results of the descriptive analysis of CT skills from PSTs (average pretest-posttest score and category). In the experimental and control groups, the CT skill (pretest) scores both indicated they fell in the 'less critically' category, while their CT skill (posttest) was different. The difference was that the experimental group falls in the 'very critically' category (CTs of 26.30, which was in the interval of CTs > 25.60), while the control group fell under the 'sufficient' category (CTs of 13.93, which was in the interval 12.80 < CTs ≤ 19.20). The categories of increasing CT skill scores from the two were also quite far apart. The experimental group was in the 'high' category (n-gain = 0.73), while the control group was in the 'low' category (n-gain = 0.14). The results in Table 5 are visualized as in Figure 3.

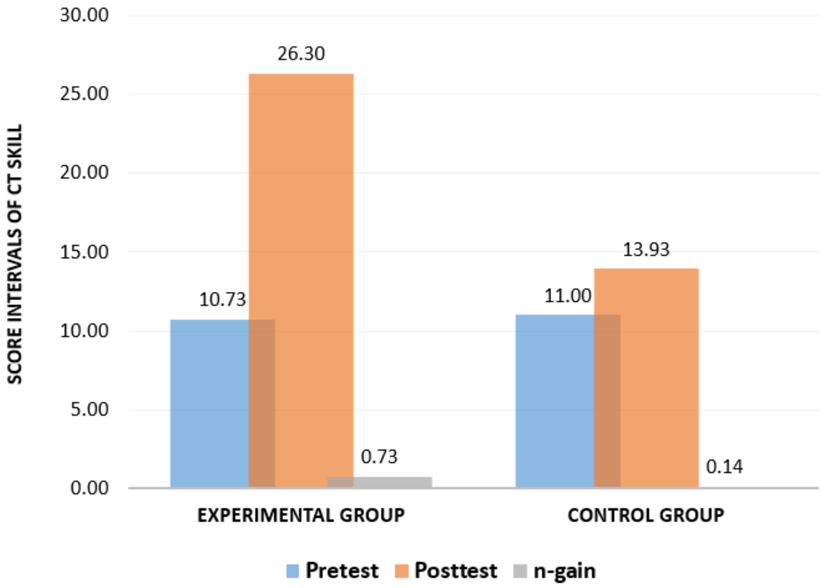

Figure 3. The CT skill measurement results from the experimental and control groups

Nased on the results of the descriptive analysis in Table 5, it can be concluded that the CT skill performance of the PSTs in the experimental group (virtual simulation-assisted remote inquiry) was better than the control group (online learning without inquiry and simulation). Furthermore, the difference in the increase in scores in the two groups was tested statistically. The results of the normality test of the data in the two sample groups based on the n-gain parameter are presented in Table 6, and the results of the different test are presented in Table 7.

Table 6. Normality test results based on the n-gain parameter, $p > .05$

Group	Statistic	df	Sig.	Annotation
Experimental	0.942	30	0.106	Normal distribution
Control	0.967	30	0.452	Normal distribution

Table 7. Different test results using independent sample t-test, $p < .05$

Variable	Var. Assumption	Levene's Test		t-test for Equal. of Means		
		F	Sig.	t	df	Sig. (2-tailed)
CT Skills	Equal var. assumed	0.057	0.811	41.623	58	0.000
	Equal var. not assumed			41.623	57.508	0.000

The results of the data normality test based on the n-gain parameter ($p > 0.05$) show that both groups of data were normally distributed (see Table 6). Based on the output in Table 7, it was found that the significance value for Levene's test was > 0.05, so that the interpretation of the independent sample t-test output was guided by the value contained in equal variances assumed with the significance (0.000) < 0.05. This means that H_0 was rejected and H_a was accepted, or there was a significant difference in the improvement of CT skills between the experimental and the control groups. If confirmed with the data results in Table 5, it is very clear that virtual simulation-assisted remote inquiry was better in supporting the CT skill performance of PSTs, when compared to online learning without inquiry and simulation applied to the control group.

The findings in this study reveal that distance inquiry learning was not an obstacle in promoting PSTs' CT skills, most importantly, remote inquiry combined with virtual simulation. The presence of technology in remote inquiry learning can cultivate students' higher-order thinking skills, especially CT (Novitra et al., 2021), while the use of virtual simulation in learning can increase deep conceptual understanding and high-level cognitive skills (Husnaini & Chen, 2019). CT acquisition can be further enhanced by involving virtual simulation in remote inquiry (see the framework in Figures 1 and 2). Conceptual formation and application of concepts are present in remote inquiry with the help of virtual simulation. This strengthens the opportunities for PSTs to practice their CT skills. Virtual simulations can replace real laboratory functions, and are even better applied when teaching very abstract material, for example in the context of a Fourier transform course. The findings of this study are in line with the findings of previous studies (T.-L. Lai et al., 2022), that inquiry combined with a virtual lab has a broad impact on improving students' thinking performance and learning outcomes.

Another study in remote-inquiry found that virtual simulations eased teachers to make instructional arrangements, and increased students' conceptual understanding of the subject matter of learning and maintained their learning motivation (Cook, 2022). Learning with virtual simulation is an integrated inquiry learning mode that can provide space to create a more interesting learning environment for students (Hovardas et al., 2018). The results of our current study are also reinforced by the findings of Brinson (2015) who synthesized empirical studies on virtual simulations, where almost all categories of learning outcomes (topic knowledge, content understanding, inquiry skills, analytical skills, scientific communication, social skills) can be trained by virtual simulation. Finally, virtual simulation as a form of learning technology development can provide full support to support the sustainability of STEM teaching (Delgado & Krajcik, 2010), and the existence of virtual simulation technology as a transformation in inquiry teaching that is more effective in achieving the expected learning goals (Radhamani et al., 2021).

CONCLUSION

The findings provide strong evidence that virtual simulation-assisted remote inquiry has a significant impact on improving PSTs CT skills in Fourier transform courses. When compared to online learning without inquiry and simulation, virtual simulation-assisted remote inquiry learning was significantly better. Conceptual formation and application of concepts are present in virtual simulation-assisted remote inquiry. This strengthens the opportunities for PSTs to practice their CT skills. This finding is valuable to support a better learning rhythm, especially to teach abstract concepts such as the Fourier transform. Finally, the findings can also become a reference for the application of virtual simulation-assisted remote inquiry in future learning routines.

RECOMMENDATION

Future work is important to explore other essential skills besides critical thinking that could potentially be trained by implementing virtual simulation-assisted remote-inquiry.

Author Contributions

The authors have sufficiently contributed to the study, and have read and agreed to the published version of the manuscript.

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Declaration of Interest

The authors declare no conflict of interest.

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