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Analyzing STEM Students' Critical Thinking Performance: Literacy Study on the Polymer Film Fabrication Process Irradiated with Gamma Rays

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Abstract

The reliability of pedagogical practice is highly dictated by how it enhances science, technology, engineering, and mathematics (STEM) students' critical thinking achievement. Adequate pedagogical practice is thus needed in line with the demands of STEM learning in the 21st century, namely achieving optimal critical thinking. This paper reports this pedagogical practice on a topic of polymer film fabrication irradiated with gamma rays. The specific objective was to analyze STEM students' critical thinking performance in literacy of the aforementioned topic. It is an exploratory study with an experimental method. Only one treatment group was involved, they were STEM students attending the Material Physics Courses. By employing valid critical thinking instruments and adequate methods of analysis, the findings show that literacy on the assigned topic significantly improved STEM students' CT skills. It was proven that the mean scores of CT indicators have increased in all aspects of the CT assessed. The statistical analysis confirmed that there were significant differences in the CT skills of STEM students between the observations before and after the learning process intervention. The implication of this study is that pedagogical interventions integrated with studies on advanced material modification technology could be effectively used for creating inspiring STEM learning, especially for training STEM students' critical thinking ways.

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INTRODUCTION

A new approach is needed in learning science, technology, engineering, and mathematics (STEM), and its relevance should align with current technology development. Developing new and adequate approaches to STEM learning is a quick response to achieving learning goals in the 21st century (Verawati, et al., 2022). One of the goals of STEM as an education system and modern pedagogical approach is as an essential point for developing skills such as problem-solving, creativity, and critical thinking in individuals engaged in it (Belbase et al., 2021). These skills are necessary for students' future career success (Perignat & Katz-Buonincontro, 2018). Therefore, the STEM approach is not only an instructional strategy but an inspiring innovation (Liao, 2019) and a path of educational transformation for community development (Belbase et al., 2021). In addition, advances in STEM education are claimed to be a critical point in solving problems in an increasingly complex world (Hartshorne et al., 2019).

STEM students' critical thinking performance now becomes the spotlight. It is related to the interaction and involvement of STEM students in learning (Kong & Mohd Matore, 2022), where the conduct of an unattractive learning process has a major impact on the performance of their critical thinking skills (Ali et al., 2021). This also has an impact on reducing student interest in being involved in the STEM field (Kang, 2019). The effective learning methods to train thinking skills in STEM are still inadequate (Chan & Nagatomo, 2022). Big attention has been paid to STEM teaching by teachers who do not have good knowledge of the effective pedagogical strategies demanded in STEM teaching (Huang et al., 2022). On the one hand, the main priority of the applied pedagogical system is that it can effectively promote students to become critical thinkers (Hagerman et al., 2022). Previous studies have recommended that the STEM learning process be conducted more systematically to train students' thinking skills (Mater et al., 2020). One of the pedagogical practices closely related to training STEM students' ways of thinking is encouraging their literacy skills (Hubbard, 2021). Literacy practices align with what is built and expected for individual student engaged in STEM (Tucker-Raymond & Gravel, 2019).

Complementary fields of knowledge in STEM aim to produce innovative products (Costantino, 2018). Product innovation is related to engineering systems and fabrication processes. Scientific literacy in the material fabrication process is one of the promotional activities in the STEM field (Dreessen & Schepers, 2019). It spans multiple fields along with the flexibility of the STEM curriculum. For instance, in the material physics course, researchers teach the process of fabricating advanced materials, namely polymer films irradiated with gamma rays. There are many difficulties when STEM students are asked to think about the fabrication process, especially if they only perform it theoretically. They need to be literate in studies directly related to polymer film fabrication. They participate in experimental activities on the polymer film fabrication process irradiated with gamma rays. Improvising deeper literacy is done using a series of result analyses of the research reports. An experience-based approach that invites STEM students to conduct a series of scientific literacy activities has been found to have the potential to train their CT skills (Clark et al., 2015).

Studies on the STEM field of polymer film fabrication process irradiated with gamma rays have been carried out, including our recent studies (Doyan et al., 2021; Susilawati et al., 2021; Verawati, 2020). To date, adequate references on how knowledge transfer is conducted in STEM learning and education have not been found. Meanwhile, what has been carried out so far has only been limited to training programs in STEM education (Aydin Gunbatar et al., 2022) which are not even integrated with studies conducted by lecturers. However, every study conducted by lecturers produces new knowledge, and each piece of new knowledge must be appropriately informed and understood by students as an asset for future change. Even, every dimension of the learning process, both curriculum and learning content in STEM, must be integrated with studies conducted by lecturers. Therefore, researchers took the initiative to transfer knowledge to STEM students in Material Physics Courses by inviting them to literate the process of fabricating polymer films irradiated with gamma rays, explicitly aiming to train their CT skills.

Literature Review

Critical thinking

Critical thinking is synonymous with reflective thinking per what was echoed by Dewey (1910). The most general definition or concept of critical thinking is from Robert Ennis. He describes CT as reasonable and reflective thinking that focuses on deciding what to believe or do (Ennis, 2011). Several well-known thinkers in the field of cognitive psychology describe more detailed characteristics of critical thinking. For example, Facione (2020) includes the processes of interpretation, analysis, evaluation, inference, explanation, and self-regulation as core aspects of critical thinking. Elder and Paul (Elder & Paul, 2012) view critical thinking as a skillful way of thinking about any problem with the intellectual use inherent in that person, so the skills inherent in critical thinking require arts or skills in adequate analysis and evaluation.

Knowledge of specific topics is essential for developing critical thinking skills (Halpern & Sternberg, 2020). Therefore, critical thinking is considered a dimension of cognitive processes, especially how learners can analyze, interpret, explain, induce/deduce, and make inferences (Abrami et al., 2008; Davies & Barnett, 2015). Reviews of the existing literature on critical thinking show different perspectives from experts and researchers. Their definition refers to the approaches employed, namely the philosophical approach, the cognitive psychology approach, and the educational approach (Verawati, Ernita, et al., 2022). However, the characteristics appearing most intensively and are widely employed and characterize the need for cognitive skills in critical thinking are analysis, inference, evaluation, and decision-making skills (Prayogi et al., 2018a; Prayogi & Verawati, 2020; Verawati et al., 2020, 2021; Wahyudi et al., 2018, 2019). The current study applies these four indicators to assess STEM students' CT skills.

Polymer film fabrication irradiated with gamma rays

Polymer films irradiated with gamma rays were developed for various needs. Its development is aligned with the development of new technologies in polymer film modification techniques. Some of the applications of polymer film technology that are developing are optical and electrical devices (Sannasi et al., 2015), photovoltaic devices (Son et al., 2011), rechargeable batteries (Rehan, 2003), and diode devices of light emitters (LEDs) (Grimsdale et al., 2009). In addition, conductive polymer films have also been applied in various health fields (Guler et al., 2014; Oyman et al., 2014).

Our recent study carried out the fabrication and modification of polymer films irradiated with gamma rays as gamma radiation dosimetry (Doyan et al., 2021). The fabrication process starts with the preparation of polymer films from polyvinyl alcohol (PVA), trichloroethylene (TCE), and cresol red dye (CR) materials. They are processed through a chemical process using the solvent-casting method (Susilawati et al., 2021) to produce film polymer samples. The polymer film samples were then irradiated with gamma rays at different doses (ranging from 0 to 12 kGy), resulting in a color change or degradation, indicating a change in the optical characteristics of the polymer film. The process is shown in Figure 1.

Changes in the optical characteristics of polymer films irradiated with gamma rays then become materials for further analysis on absorption spectra, optical absorption dose-response, absorption edge, activation energy, and band gap energy, respectively. The process of fabricating polymer films irradiated with gamma rays is taught in Materials Physics Courses on advanced material processing materials. From the analysis of the findings related to the optical characteristics of polymer films, STEM students then carry out in-depth literacy in the fabrication process and analyze the results obtained. From this process, researchers emphasize ways of in-depth analysis so that the critical thinking performance of STEM students can be developed.

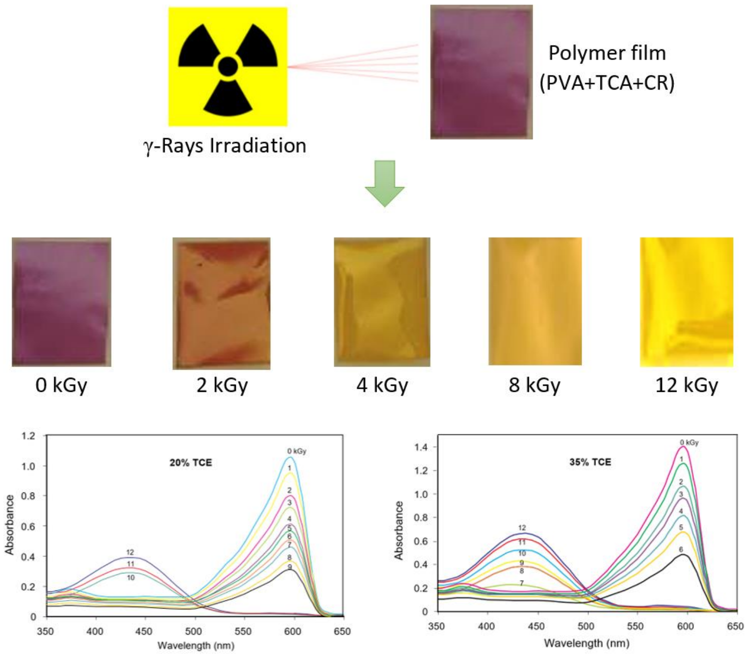


Figure 1. Fabrication polymer film process and optic response

METHOD

Research background and design

This study was initiated based on studies conducted by lecturers on the fabrication of polymer films irradiated with gamma rays. The results were then documented in the form of research reports. The research and results were then integrated with the learning process in the material physics course attended by STEM students. The background, methods, and research data were presented in the learning process on fabricating polymer films irradiated by gamma rays. From the presentation of research data, STEM students were asked to complete tasks or questions that require critical thinking skills, especially those related to changes in the optical characteristics of polymer films irradiated with gamma rays. Previously, observations were done in terms of students' critical thinking skills and topics related to polymer film fabrication irradiated with gamma rays. This study was closer to exploratory research using experimental methods, using a pretest-posttest group design (O_1 - X - O_2). Only one treatment group was prepared. The group consisted of STEM students taking Material Physics Courses. Critical thinking skills were observed as a pretest - O_1 and posttest - O_2.

Participants

The participants in this study were 26 STEM students taking materials physics courses at the Faculty of Applied Science and Engineering at Mandalika University of Education, Indonesia. Participant demographics are presented in Table 1.

Table 1. Participant demographics

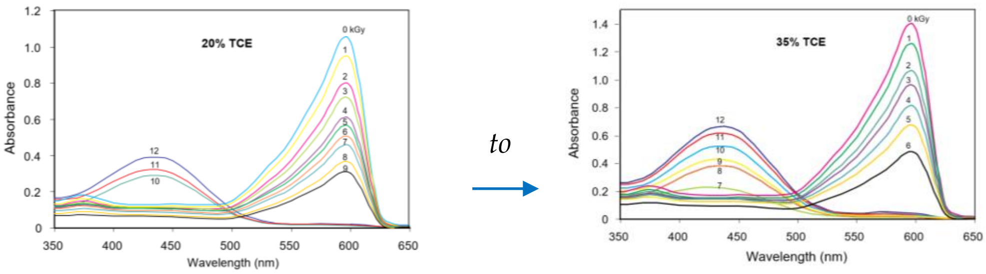
Participant Characteristics		Quantity (n)	Percentage (%)
Gender	Female	10	38.5
	Male	16	61.5
Age (year)	< 19	2	8
	19 – 20	24	92
	> 20	0	0

The involvement of STEM students as participants and the implementation of the study had obtained academic permission from the Institute for Research and Community Service (LPPM Mandalika University of Education).

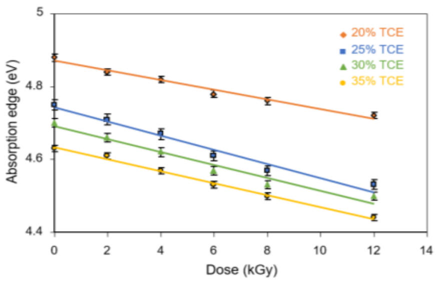
Research Instruments

STEM students' critical thinking skills were measured based on indicators related to analysis, inference, evaluation, and decision-making. The learning task was broken down concerning literacy in the polymer film fabrication process irradiated with gamma rays from these four indicators. An example of a critical thinking skills test instrument on the analysis indicators is as follows.

The following shows the absorbance spectra of PVA-TCE-CR polymers film containing 20% to 35% TCE composition when irradiated γ-rays at various doses (in kGy).



Resulting graph plots of the absorption edge of PVA-TCE-CR polymer film composites as a function of dose for different TCE compositions:



The absorption edge decreases *with increasing TCE composition and increasing dose of γ-rays irradiated. Analyze these results according to corresponds to the excitation of outer electrons attributed to the electronic transitions of electrons!*

Data Analysis

Referring to the four CT indicators employed, eight essay test instruments were prepared (one CT indicator is distributed into two test items). The scoring technique refers to previous studies (Prayogi et al., 2022; Verawati, Harjono, et al., 2022), where the range of scores for each test item was 0 (lowest score) to +4 (highest score). CT skills were categorized into criteria from not critical to very critical. The intervals of these criteria are shown in Table 2. The parameters used are CT indicators (CTi) and individual CT (CTid).

Table 2. Categories and CT skills interval based on CTi dan CTid

Category	Interval score of CTi	Interval scores of CTid
Very critical	CTi > 3.21	CTid > 25.60
Critical	2.40 < CTi ≤ 3.21	19.20 < CTid ≤ 25.60
Quite critical	1.60 < CTi ≤ 2.40	12.80 < CTid ≤ 19.20
Less critical	0.80 < CTi ≤ 1.60	6.41 < CTid ≤ 12.80

Category	Interval score of CTi	Interval scores of CTid
Not critical	CTi ≤ 0.80	CTid ≤ 6.41

The increase in CT skill scores was analyzed descriptively using the normality gain (n-gain) formulation (Hake, 1999). Meanwhile, statistical analysis (difference test) was used to measure the difference in the improvement of CT scores between the pretest and posttest ($p < .05$). The hypothesis was that there were differences in CT skill scores between the pretest and posttest which indicated the success of the intervention.

RESULTS AND DISCUSSION

The CT skills of STEM students were analyzed in the current study. The parameters used were CTi and CTid. The CT skills of STEM students based on the CTi parameters are presented in Figure 1. In the four aspects of the CTi skills measured (analysis, inference, evaluation, and decision-making), all of those experienced an improvement in the CT skill scores.

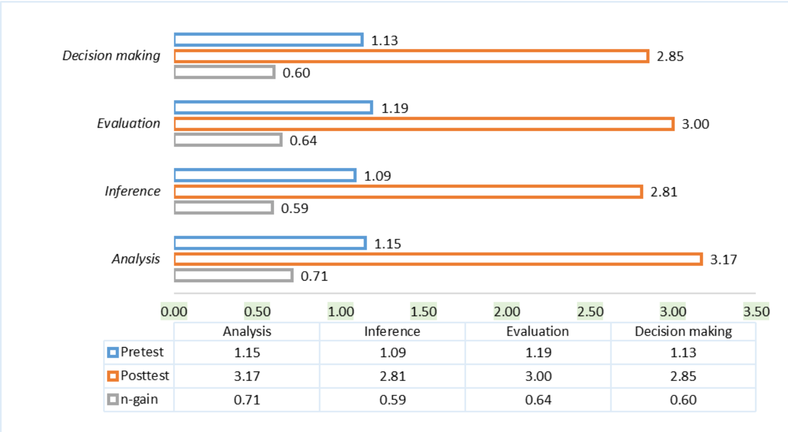


Figure 1. STEM students' CT skills based on CTi parameters

The average pretest score was 1.14 (less critical). After the learning intervention, the average post-test was 2.96 (critical). The increase of the average score (n-gain) of CTi was 0.64 (moderate). The performance of increasing the CT skills score in the analysis aspect was 0.71 with the criterion "high," and it was the most prominent compared to other CTi aspects. The increase of the CTi scores in the aspects of inference, evaluation, and decision-making were 0.59, 0.64, and 0.60 respectively with moderate criteria. Furthermore, the CT skills of STEM students based on CTid parameters are presented in Figure 2.

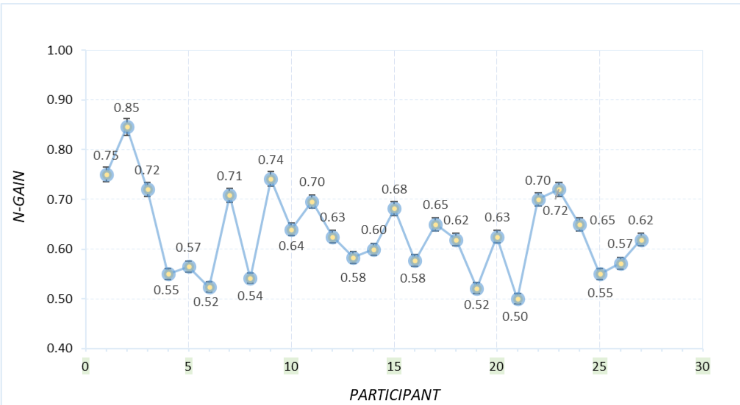


Figure 2. STEM students' CT skills based on CTid parameters

Based on the CTid parameter, Figure 2 show the average pretest score of 9.11 with the "less critical" criteria. After the learning intervention, the score increased to 23.67 with the "critical" criteria. The distribution of the increase of the CTid score (n-gain) varied greatly among the 27 STEM student participants. The highest n-gain score was 0.85 (high), and the lowest n-gain was 0.50 (moderate). The average CTid n-gain score accumulatively was 0.63 with the criteria of "moderate." The difference in CTid scores between the pretest and posttest was then statistically evaluated (difference test) preceded by a data normality test. The results are presented in Table 3 and Table 4.

Tabel 3. Results of data normality test

Group		Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
CTid	Pretest	.174	27	.034	.907	27	.020
	Posttest	.181	27	.023	.931	27	.074

The results of the data normality test indicated that one of the data groups was not normally distributed, and did not meet the sig parameter. > 0.05 as a condition for normality. Therefore, the test was continued with a nonparametric differential test using the Wilcoxon test.

Tabel 4. Results of Wilcoxon test

		N	Mean Rank	Sum of Ranks	Z	Asymp. Sig. (2-tailed)
Group - CTid	Negative Ranks	54	27.50	1485.00	-6.400	.000
	Positive Ranks	0	.00	.00	-	-
	Ties	0	-	-	-	-
	Total	54	-	-	-	-

The results of the Wilcoxon test showed sig. <p (0.05). It means there was a significant difference in the CT skills of STEM students between the pretest and posttest. The finding also confirms Ha was accepted. It means that there are differences in CT skill scores between the pretest and posttest, which indicate the success of the learning intervention (treatment) in improving the CT skills of STEM students.

The study's results conclusively show that literacy about the polymer film fabrication process irradiated with gamma rays significantly improved the CT skills of STEM students. The indication is that the average CTi score has increased in all aspects of CT measured. The most remarkable increase was in analysis with an n-gain score of 0.71 with high criteria. Strengthening the literacy aspect was found to impact improving analytical skills strongly. Analytical abilities guarantee the achievement of more mature critical thinking (Bilad et al., 2022). Previous studies included aspects of analysis as a benchmark for assessing learning outcomes in the experimental process (Carmona et al., 2022). Researchers found almost no specific references on how the literacy process in polymer film fabrication in engineering teaching has an impact on strengthening student analytical performance. But the results of the current study give confidence that literacy about the polymer film fabrication process irradiated with gamma rays has a significant impact on improving STEM students' CT skills.

Scientific literacy relates to scientific skills or a learner's capacity to use scientific knowledge. In the experimental context, scientific literacy is identified with the scientific process skills needed in how a learner makes decisions in analysis according to scientific procedures. In previous studies, scientific process skills such as interpreting, interpreting, and comparing data can encourage literacy and critical thinking in STEM students (Clark et al., 2015). Students are invited to carry out in-depth analyses in the context of literacy about fabricating polymer films irradiated with gamma rays. After irradiating the polymer films, the material analysis encompasses the changes in the optical characteristics of the polymer films, the absorption spectral pattern formed, the optical absorption dose-response, absorption edge, activation energy, and band gap energy. Finally, every analysis method shown by students directly is directed to sharpen their critical thinking skills. Our current study is part of an experiential learning approach that is much needed in STEM learning that can train critical thinking. Analytical and critical methods are needed by each individual working in the STEM field to support their technical and practical skills (Perignat & Katz-Buonincontro, 2018).

In our current study findings, it is undeniable that scientific literacy in the material fabrication process can train the thinking skills of STEM students. Experimentation and literacy are ways of cultivating the process skills that STEM students expect. On the one hand, the design of STEM activities related to renewable energy sources is motivating and exciting for them to learn and can foster their critical thinking (Hiğde & Aktamış, 2022). Evidence showed that pedagogical interventions can follow the current technology development (Gibson, 2001). In addition to training critical thinking, conducting STEM activities based on advanced material modification technology is an effort to create inspiring STEM learning. It is a goal expected in STEM education as inspiration for innovation (Liao, 2019).

CONCLUSION

An analysis study of STEM students' critical thinking performance was carried out through literacy studies in the polymer film fabrication process irradiated with gamma rays. The study's results conclusively show that the literacy on the assigned topic significantly impacted STEM students' CT skills. The mean scores of CT indicators increased in all aspects of measured CT skills. Statistical analysis confirmed a significant difference in the CT skills of STEM students between the pretest and posttest. It also confirmed that Ha was accepted. It means there are differences in CT skill scores between the pretest and posttest, indicating the intervention's success (learning treatment) in improving STEM students' CT skills. This study implies that pedagogical interventions should be applied in line with technology development, where the conduct of STEM activities based on advanced material modification technology is an attempt to create inspiring STEM learning to train STEM students' critical thinking ways.

RECOMMENDATION

Training critical thinking for STEM students must be carried out continuously. Tutors or lecturers have a great responsibility in carrying out this CT practice. Future studies are essential to continue intervening in pedagogical practices integrated with lecturer studies that impact the involvement of STEM students in critical thinking.

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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