Eclética Química

Articles in education in chemistry and chemistry-correlated areas

revista.iq.unesp.br

| Vol. 48 | n. 3 | 2023 |

The potency of cooperative integrated reading and composition in building chemistry students' scientific literacy and self-regulated learning

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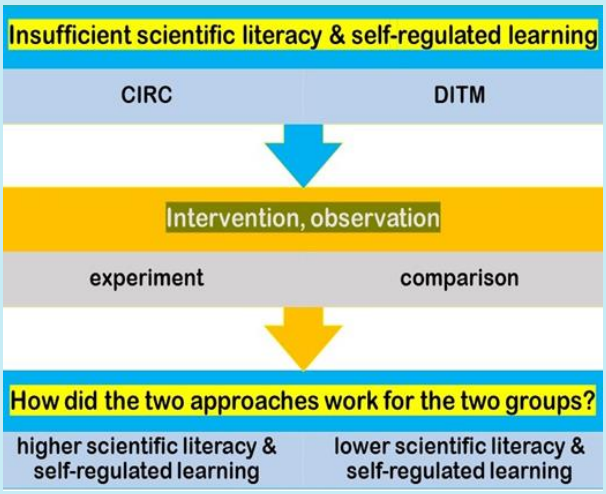
ARTICLE INFO

Article history:
Received: October 02, 2022
Accepted: April 12, 2023
Published: July 01, 2023

Section Editors: Assis Vicente Benedetti
0

Keywords:
1. autonomous learner
2. colligative properties
3. cooperative learning
4. Direct Instructional
5. PISA result

ABSTRACT: The effect of the Cooperative Integrated Reading and Composition (CIRC) approach on scientific literacy and students' regulated learning in colligative properties of solution was explored. The contribution of the CIRC approach was measured by investigating whether the improvement in scientific literacy and regulated learning of the CIRC students are more significant than the improvement for students with the Direct Instructional Teaching Method (DITM) after experiencing two different teaching approaches. Two groups of students (experiment and comparison) from a public senior high school in East Java, Indonesia, were involved. The experimental group experienced the colligative properties of solution with the CIRC teaching approach, while the comparison group experienced the DITM one. We found that scientific literacy and self-regulated learning of students with CIRC are higher than students with DITM, implying the potency of this approach to be applied to other chemistry topics. This study indicates that CIRC could be used to improve students' scientific literacy and self-regulated learning for other chemistry topics. The implication of this study for teaching colligative properties of solution is also discussed.



Eclética Química, vol. 48, n. 3, 2023, 27-35
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.3.2023.p27-35

1. Introduction

Educational institutions in the current era are demanded to provide a learning environment supporting the development of students' soft skills that meet the 21st-century skills requirement. Soft skills, also known as behavioural skills, play a crucial role in personal growth that is more nebulous than hard skills (Almeida and Morais, 2021). Their definition is contested, but Cimatti (2016) links them to empathy and problem-solving, such as emotional intelligence, teamwork, time management, resilience, and intuitive thinking. Although their roles in the academic field have not been systematically uncovered, the pivotal support in other aspects of life has been confirmed (Feraco *et al.*, 2022). Several soft skills have been considered essential to be mastered by students, including scientific/chemical literacy ability (Cigdemoglu *et al.*, 2017; Kohen *et al.*, 2020; Suwono *et al.*, 2022; Wei and Lin, 2022), communication skill (Chung *et al.*, 2016; Kleckner and Butz, 2022; Skagen *et al.*, 2018), collaborative skill (Heeg *et al.*, 2020; Kumar *et al.*, 2022; Reid *et al.*, 2022), and self-regulated learning (Austin *et al.*, 2018; Eklund and Prat-Resina, 2014; Seibert *et al.*, 2021).

Scientific literacy is the capacity to use scientific knowledge, identify questions and draw evidence-based conclusions to understand and help make decisions about the natural world and its changes through human activity (PISA, 2004). It is also defined as the capacity to comprehend scientific processes and interact meaningfully with everyday scientific information (Fives *et al.*, 2014). The United Nations Educational, Scientific and Cultural Organization (UNESCO) has emphasised that all educational institutions should cultivate students' scientific literacy (Nogueira *et al.*, 2021). Building students' chemical literacy should be the paramount goal of science education teaching in this era (Kohen *et al.*, 2020). Scientific literacy should also emphasise the character and values that lead students to make the right decisions for a sustainable planet and the protection of fundamental human rights for all (Choi *et al.*, 2011). Remarkably, the significant contribution of scientific literacy skills to foster the economic growth of a developing country like Indonesia is highly considered (Laugksch, 2000). These statements imply that scientific literacy is an essential skill to be held by students.

With the ultimate goal of arriving at the golden generation by 2045, Indonesia should ensure that current Indonesian students exhibit sufficient scientific literacy skills. Human resources in this generation will hold sufficient soft skills to contribute optimally to the country's development. However, the lack of students' scientific literacy has challenged science learning in Indonesia (Sari *et al.*, 2017). The current Programme for International Student Assessment (PISA) survey in 2018 put Indonesian scientific literacy ability within the lower rank (70) among 78 participant countries (PISA, 2018). The result of this survey fits with the findings of several studies in this area. Adnan *et al.* (2021) found that secondary school students in South Sulawesi, Indonesia, demonstrated low scientific literacy skills. Even first-year students have shown only a moderate level of chemical literacy (Djaen *et al.*, 2021). Islami *et al.* (2020) compared the level of scientific literacy skills between novice Indonesian and Thailand science teachers and found that Thai teachers demonstrated a slightly higher performance. This result is supported by the evidence that Indonesian students' mastery of the content, processes and contexts of scientific phenomena is considered insufficient (Rochman, 2015). The domination of the Direct Instructional Teaching Method (DITM) in many chemistry classes in Indonesia may contribute to this issue (Fuadi *et al.*, 2020).

Another valuable skill for students is the ability to learn independently or through self-regulated learning. In some literature, self-regulated learning is also called learning autonomy (Eklund and Prat-Resina, 2014). Such ability allows students to monitor, control and regulate their cognition, motivation, and behaviour (Saribas and Bayram, 2009; Schunk, 2011). Self-regulated learning is characterised by the reflective application of suitable techniques in each learning circumstance, as well as motivational and metacognitive regulation on the side of the students (Seibert *et al.*, 2021). Students are intrinsically driven to study in order to self-regulate; this is a fundamental component of theories on self-regulated learning (Austin *et al.*, 2018). Several studies uncovering the role of self-regulated learning are found in the literature. Hermanns and Schmidt (2019) found that the stepped tool effectively improved students' self-regulated learning and ability to solve chemistry questions. Another study involving thousands of students taking organic chemistry found that those with self-regulated learning demonstrated higher achievement (Austin *et al.*, 2018). Talanquer (2010) summarised a slightly different perspective in which students who generate explanations for themselves while studying or solving problems can gain a deeper understanding of the subject matter and improve knowledge transfer. We firmly believe that self-generated explanation is also connected to self-generated learning. This claim is built upon the consideration that self-directed students successfully transfer their knowledge and abilities to new contexts (Sperling *et al.*, 2016).

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In considering the essential role of self-regulated learning, some efforts to promote it have been found. Using inquiry based-learning, Seibert *et al.* (2021) promoted students' self-regulated with Multitouch Experiment Instructions in School Laboratories. In other studies, the stepped tool was also employed to facilitate self-regulated learning in organic chemistry classes (Hermanns and Schmidt, 2019); a virtual lab with inquiry-based learning enhanced scientific literacy in optics and light (Putri *et al.*, 2021); and problem-based learning was also applied to improve students' problem-solving and learning autonomy (Kurniawati, 2022).

Chemistry teaching should be carried out in a way to promote students' scientific/chemical literacy and self-regulated learning. Cigdemoglu and Geban (2015) revealed the effectiveness of a context-based approach in improving students' scientific literacy on the topic of chemical thermodynamics. Scrum methodology could also enhance students' scientific literacy (Vogelzang *et al.*, 2020). Inquiry based-learning has been applied to promote students' self-regulated learning (Kurniawati, 2022; Putri *et al.*, 2021). Drawing a conclusion from the previous strategies indicates that some strategies could be employed to improve students' scientific literacy and self-regulated learning. As the interactive compensatory learning model suggests, no single skill can completely support or obstruct self-regulated learning (Hubbard *et al.*, 2019).

In this study, we implemented a Cooperative Integrated Reading and Composition (CIRC) approach to promote students' scientific literacy and self-regulated learning on colligative properties of solutions. CIRC is a methodology in which students are divided into groups to cooperatively learn the relevant concepts (Mubarok and Sofiana, 2017). This model is designed to develop reading and writing abilities essential for supporting scientific literacy skills (Durukan, 2011). Even though this strategy is mainly implemented in the area of social science and literature, its contribution to the area of science education has also been uncovered. Ristanto *et al.* (2021) revealed that CIRC effectively improved students' conceptual understanding of the excretory system. In chemistry, implementing CIRC also improved students' achievement and motivation (Masnaini *et al.*, 2018). In addition, improving reading skills, one of the advantages of using this strategy helps to improve students' understanding and scientific literacy. To sum up, the primary purpose of this study is to investigate the difference in scientific literacy and self-regulated learning between CIRC and DITM students.

2. Experimental

2.1 Research Design

This *quasi-experimental design* employed a *post-test-only control group design* and involved two groups of students (67 in total). The students were chosen because they will embark on the colligative properties of solution class. The group that experienced the CIRC teaching approach is the experimental group, while the other with DITM is the comparison group. The two groups of students were selected using the convenience sampling technique. The school provided two groups without allowing the authors to choose other groups. Such a procedure in which respondents cannot be randomly obtained is called convenience sampling (Fraenkel *et al.*, 2011). Post-test aiming to measure the improvement of students' scientific literacy was performed after finishing the interventions (CIRC and DITM) for the two groups. The assigning procedure for the experiment and comparison groups was determined randomly after considering that the initial ability of the two groups was equal. Normality employing Kolmogorov-Smirnov and *Independent Sample T-Tests* were applied to confirm the equal initial ability of the two groups. Calculating the two tests were carried out using the software SPSS for Windows. Students' average chemistry grade from the previous term was the basis for determining students' initial ability.

2.2 Instrumentation

Scientific literacy in colligative properties of solution test (SC-CPST) was applied in the post-test to measure the improvement of students' scientific literacy after interventions. Meanwhile, students' self-regulated learning was identified using an observation sheet assessment during the interventions. Meanwhile, students' Self-Regulated Learning-Observation Sheet Assessment (SGL-OSA) was identified during the interventions. Both instruments were developed by the authors and were validated before being used for data collection. The instruments have not been used in any previous study. The validation covered content, construct, and face validities involving the chemistry lecturer and school chemistry teacher. They provided feedback on the content, its relevance to secondary school students' cognitive level, and the language. Their feedback was taken into account for refining the final instrument for data collection. The interventions (CIRC and DITM) were carried out for three meetings with

Eclética Química, vol. 48, n. 3, 2023, 27-35
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.3.2023.p27-35

100 min each. The post-test was conducted three days after the last meeting of the interventions for 90 min.

2.3 Data Analysis

Students' scientific literacy in the topic of colligative properties of solution for the two groups was measured using the SC-CPST instrument at the post-test. The students' scientific literacy level was classified according to the Organisation for Economic Co-operation and Development (OECD) parameter presented in Table 1 (PISA, 2016). The difference in scientific literacy level between the two groups was measured using the *independent sample t-test* after meeting the normality test as a prerequisite procedure.

Table 1. The three domains for classifying students' scientific literacy levels.

Domains	Indicators
Explaining the phenomenon scientifically	Identify, offer, and evaluates the explanation of various natural and technological phenomena.
Evaluating and designing scientific questions	Describe and assesses scientific investigations and propose ways of answering questions scientifically.
Interpret data and evidence scientifically.	Analyse and evaluate data, claims and arguments in various representations and draw appropriate scientific conclusions.

Source: Retrieved from PISA (2016).

Meanwhile, students' self-regulated learning was observed during the interventions that involved seven well and equal trained observers. The parameter to classify it is presented in Table 2 (Azwar, 2009). An observation sheet with five Likert scales contains five indicators: initiative, creativity, innovation, improvisation, and proactiveness. The complete instrument is available on request.

Table 2. Students' self-regulated learning parameter.

Score Interval	Category
$X < Mi - 1.5\ SDi$	Very Low
$Mi - 1.5\ SDi < X \leq Mi - 0.5\ SDi$	Low
$Mi - 0.5\ SDi < X \leq Mi + 0.5\ SDi$	Medium
$Mi + 0.5\ SDi < X \leq Mi + 1.5\ SDi$	High
$Mi + 1.5\ SDi < X$	Very High

Note: $Mi = (X_{max} + X_{min})\frac{1}{2}$; $SDi = (X_{max} - X_{min})\frac{1}{6}$

Source: Elaborated by the authors using data from Azwar (2009).

3. Results and discussion

3.1 Comparing students' science literacy between the two groups

To determine whether the CIRC is influential in improving students' scientific literacy, the gained scientific literacy scores between the two groups were compared. The higher contribution of the CIRC teaching method in improving students' scientific literacy compared to DITM is indicated by the different scores when answering SC-CPST questions. The average score of CIRC students was 82.06, which is higher than that of DITM students with 64.00. The statistical procedure (independent t-test) confirms the difference of 0.000 significance value. Masnaini *et al.* (2018) found the superiority of CIRC to DITM in improving chemistry students' achievement. In teaching the excretory system in Biology class, CIRC students also demonstrate better performance than DITM students (Ristanto *et al.*, 2021). This difference implies that CIRC is more potent in improving students' scientific literacy. In addition, this study also indicates that CIRC applies not only to social and language literature but also to basic science disciplines, including chemistry, biology, and physics. Therefore, for basic science fields, we encourage the implementation of this strategy for teaching a topic with coverage of many factual information and rules, such as hydrocarbon.

The discrepancy in scientific literacy between both groups can also be identified from their responses explaining the sugar solution's increase in the boiling point. Figure 1 depicts how CIRC students explain why the boiling point of sugar solution is higher than its pure solvent (water, H_2O). The CIRC student explained that (*in English translation*) "the sugar molecules prevent the process of water evaporation from equalizing the external pressure, so a bigger temperature is required for it." His/her answer (Fig. 1) reflects that he/she harboured a scientific literacy domain, "explaining phenomena scientifically." Describing or interpreting phenomena scientifically, predicting changes, and identifying appropriate descriptions, explanations, and predictions are all aspects of this framework (Tsai, 2015). Figure 1 depicts that the student can explain the presence of solute molecules ($C_6H_{12}O_6$) inhibiting the evaporation of solvents (H_2O) and strengthen by stating that a higher temperature is needed to reach its boiling point.

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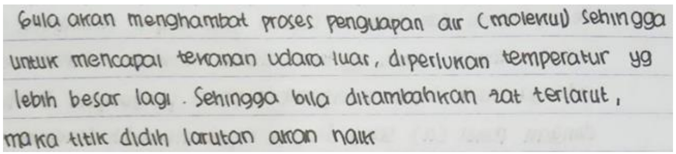
Gula akan menghambat proses penguapan air (molekul) sehingga
untuk mencapai tekanan udara luar, diperlukan temperatur yg
lebih besar lagi. Sehingga bila ditambahkan zat terlarut,
maka titik didih larutan akan naik

Figure 1. A CIRC student's explanation regarding the boiling point of sugar solution.

The different phenomena are shown by the answers of DITM students, as presented in Fig. 2. The students stated (*in English translation*) that "the increase in viscosity of solution causes the increase boiling point of a solution." The student correctly recognized that the boiling point of sugar solution is higher than that of pure water but failed to support his/her answer with scientific argumentation. The student also can calculate the increase in the boiling point of the sugar solution using mathematical equations, but again, presenting the supporting scientific explanation is missing. The student can only explain the cause from the macroscopic aspect related to viscosity. This result reflects the insufficient scientific literacy domain, particularly "explaining phenomena scientifically."

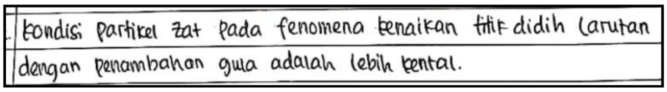
Kondisi partikel zat pada fenomena kenaikan titik didih larutan
dengan penambahan gula adalah lebih kental.

Figure 2. A DITM student's explanation regarding the boiling point of sugar solution.

The improvement of students' ability in improving their scientific literacy is also demonstrated by some students participating in special education in mathematics and science in Thailand. At the beginning of the intervention, their ability in this aspect was considered low as they argued that "polyethylene glycol 600's benefits to the environment include its low toxicity, ability to protect seeds, and low absorption into the human body." After the intervention (Science, Technology, Society, and Environment), students provided a better explanation, as presented in the following sentences: "Since it is a non-toxic water-soluble chemical to plants and the environment, physostigmine can be used instead of glyphosate products. The potential for this method to produce acidic soil is a major drawback. Soil acidification is easily remedied by amending it with lime (CaO)" (Chanapimuk *et al.*, 2018).

Another CIRC student (Fig. 3) explained (*in English translation*) that attractive interaction between water and sugar molecules hinders the vaporization of water molecules leading to higher temperatures for the solution to hit the boiling point. Meanwhile, other DITM students only mentioned that the sugar molecules affect the boiling point of the sugar solution without providing a further explanation to support it. The result of this study is in line with previous studies regarding the impact of several interventions in improving students; scientific literacy, including a context-based approach (Cigdemoglu and Geban, 2015), scrum methodology (Vogelzang *et al.*, 2020), and argumentative practice (Cigdemoglu *et al.*, 2017).

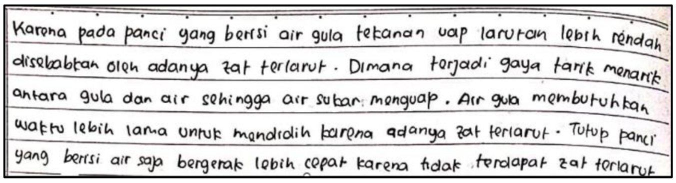
Karena pada panci yang berisi air gula tekanan uap larutan lebih rendah
disebabkan oleh adanya zat terlarut. Dimana terjadi gaya tarik menarik
antara gula dan air sehingga air sukar menguap. Air gula membutuhkan
waktu lebih lama untuk mendidih karena adanya zat terlarut. Tutup panci
yang berisi air saja bergerak lebih cepat karena tidak terdapat zat terlarut

Figure 3. Another example of a CIRC student's explanation regarding the boiling point of sugar solution.

It is essential to regularly test students' scientific literacy throughout their academic careers to see if *the seeds of literacy* have taken root in their brains (Shwartz *et al.*, 2006). Even during the emergence of COVID-19, Ramachandran *et al.* (2021) put effort into utilizing a collaborative-based learning approach, problem-solving, and understanding applied scientific data for strengthening scientific literacy through the cultivation of analytical, problem-solving, and teamwork abilities. Tsai (2015) found that students in the experimental group might have improved their PISA science competencies, including scientific literacy, after being exposed to online argumentation, which included argumentation instruction and activities. Students may benefit from learning how to use deductive and inductive reasoning through the process of constructing and defending an argument.

3.2 Students' self-regulated learning between the two groups

Students' self-regulated learning for both groups is derived from the observation sheet. Table 3 shows the significant advantages of CIRC in promoting self-regulated learning over the DITM for all indicators. The number of CIRC students demonstrating self-regulated learning behaviours is more than 20% higher than DITM students in each indicator. An enormous gap is observed in the initiative indicator. Self-regulated learning occurrences for CIRC students are about 82% on average.

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Table 3. The self-regulated learning occurrences between CIRC and DITM students for each indicator.

Category	Percentage	
	CIRC	DITM
Initiative	82.07	58.45
Creativity	81.10	61.35
Innovation	81.61	62.89
Improvisation	84.17	61.98
Pro-Activeness	82.52	62.49

For five self-regulated learning indicators, CIRC students also demonstrated better self-regulated learning. Table 4 describes that almost 80% of CIRC students demonstrated very high self-regulated learning, while none of the DITM students did so. Meanwhile, only about 61% of DITM students exhibited high self-regulated learning. The self-regulated learning of DITM students ranges from very low to medium, with an almost equal number between categories. On the contrary, none of the CIRC students exhibited a very low category of self-regulated learning. Only a tiny portion of CIRC students hold a low and medium level of self-regulated learning. These results indicate that the CIRC teaching method supports the formation of students' self-regulated learning.

Table 4. The comparison of self-regulated learning levels between CIRC and DITM students.

Category	Percentage	
	CIRC	DITM
Very Low	0	35.29
Low	12.12	26.47
Medium	9.09	38.23
High	0	0
Very High	78.78	0

The better self-regulated learning of CIRC students may explain why their scientific literacy ability is better than that of DITM students. Compared to students in the comparison group (DITM), those in the experimental group (CIRC) used metacognitive strategies more frequently; these strategies are linked to self-regulated learning and, as a result, leading to higher achievement outcomes (i.e., more correct responses and/or more thorough scientific explanations) (Kadioglu-Akbulut and Uzuntiryaki-Kondakci, 2021).

A similar finding was revealed from the study covering 2,648 organic chemistry students in which those with high achievement hold self-regulated learning (Austin *et al.*, 2018). Another study employing problem-based learning teaching approach also improved students' self-regulated learning (Kurniawati, 2022). Putri *et al.* (2021) reported the effectiveness of virtual labs with inquiry-based learning in enhancing students' scientific literacy.

The essential role of self-regulated learning has been found even beyond its contribution to the student's conceptual understanding. A study involving hundreds of Taiwanese undergraduate students uncovered the link between professional development and confidence in one's own marketability is mediated by the ability to engage in self-regulated learning (Hsu *et al.*, 2022). Individuals' optimistic outlooks on self-improvement, driven by intrinsic motivation, are aided by motivational self-regulated learning processes (Pintrich, 1999). A person's effort and persistence in learning are more likely to be exemplary when they are driven by their intrinsic motivation rather than by external pressures or rewards (Ryan and Deci, 2000). Motivated students positively view their abilities and take responsibility for their learning (Zimmerman, 1986). Students with high levels of self-efficacy (those who are confident in their abilities to succeed) may view themselves as highly employable and, as a result, have a better chance of securing a job in the future (Berntson *et al.*, 2008). Students with high levels of self-efficacy believe they can successfully complete all course requirements and view obstacles as exciting opportunities to growth (Caprara *et al.*, 2008). Uzuntiryaki-Kondakci *et al.* (2017) suggest that colleges and universities should give future educators ample chances to hone their professional content knowledge and self-regulation skills in the classroom.

4. Conclusions

This study reveals that students with the CIRC approach improved scientific literacy and self-regulated learning more than those with the DITM approach. Regarding scientific literacy, CIRC students exhibited a better performance in all three indicators, as reflected in their answers to the colligative properties of solution questions. CIRC students' explanations reflect the mastery of scientific literacy, particularly in explaining phenomena scientifically. CIRC also contributes more to students' self-regulated learning in the occurrence number and its level. Almost all the CIRC students performed self-regulated learning behaviours for each indicator.

Meanwhile, only more than half of DITM students demonstrated these behaviours for each indicator. The level of self-regulated learning for CIRC students was also mostly in the very high category, while DITM students ranged from very low to medium, and none between high and very high. The results indicate that CIRC could potentially improve students' scientific

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literacy, self-regulated learning, and other 21st-century skills. We realise that involving two groups of students is insufficient to offer a general conclusion; however, these results could be a pilot for a future study involving broader respondents and various chemistry topics. Considering the type of CIRC, it may sound like a reasonable exercise to expand this strategy for improving students' scientific literacy and self-regulated learning in chemistry topics involving many chemical facts and rules. Hydrocarbon, matter and measurements, colloidal systems, additive and food chemistry, and other similar topics are examples of chemistry topics that may suit the CIRC strategy. The result of this study also implies that students' scientific literacy and self-regulated learning can be promoted using several active learning such as a collaborative-based learning approach. Future studies to explore this suggestion will be interesting.

Authors' contribution

Conceptualization: Habiddin, H.
Data curation: Saputri, C. Y.
Formal Analysis: Saputri, C. Y.
Funding acquisition: Habiddin, H.
Investigation: Saputri, C. Y.
Methodology: Habiddin, H.
Project administration: Habiddin, H.; Saputri, C. Y.
Resources: Habiddin, H.; Saputri, C. Y.
Software: Not applicable.
Supervision: Habiddin, H.; Santoso, A.
Validation: Santoso, A.
Visualization: Saputri, C. Y.
Writing – original draft: Habiddin, H.; Saputri, C. Y.; Santoso, A.
Writing – review & editing: Habiddin, H.

Data availability statement

All data sets were generated or analyzed in the current study.

Funding

Directorate General of Higher Education, Research and Technology, Ministry of Education, Culture, Research and Technology, Republic of Indonesia. Contract Number: 092/E5/PG.02.00.PT/2022.

Acknowledgments

We thank the Directorate General of Higher Education, Research and Technology, Ministry of Education, Culture, Research and Technology, Republic of Indonesia, for funding this study through the Penelitian Tesis Magister (PTM) 2022 scheme.

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DOI: 10.26850/1678-4618eqj.v48.3.2023.p27-35