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| RESEARCH ARTICLE

Practicality Test of Learning Strategy on Chemistry Instrument Analysis to Improve Scientific Generic Thinking Skills

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| ABSTRACT
Higher-order thinking skills in chemistry learning encompass a set of skills known as science generic skills. These skills are fundamental competencies that can be applied across various scientific disciplines and contribute to the success of scientists and science practitioners. The objective of this research is to develop a Problem-Based Learning-based VC-MER learning strategy that enhances students' science generic skills. The research aims to test the practicality of the VC-MER learning strategy, based on Problem-Based Learning, in improving students' science generic skills. The results indicate that the VC-MER learning strategy is feasible for use in the learning process and can be categorized as a practical learning strategy for implementing all stages of the VC-MER learning strategy.

| KEYWORDS

Science Generic Thinking Skills, Instrument Analysis Chemistry, Development of Learning Strategies.

| ARTICLE INFORMATION

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1. Introduction

High-level thinking skills in chemistry learning encompass a set of abilities known as science generic skills (Virtayanti et al., 2019). Science generic skills, as defined by Brotosiswojo (2001), are competencies that can be applied to comprehend diverse concepts and tackle scientific problems. Prospective chemistry teachers should possess generic skills, which are basic abilities that are general, flexible, and applicable to studying higher science or serving in a broader field of science/work. These skills should not only be in accordance with their field of expertise but also other fields (Liliasari 2014; 102).

Osman (2011) suggests that learners can enhance their academic abilities and apply classroom knowledge to real-life situations through the experience of science generic skills. Binkley et al. (2012) define generic skills as including creativity and innovation, specifically the ability to work in new situations. The authors describe creativity at a more concrete level, particularly at the level of action. Generic skills refer to learning activities that involve metacognition, specifically continuous learning and self-assessment skills. These skills are considered essential components of lifelong learning (Boud, 2000; Crisp, 2012) and professional identity (Eteläpelto et al., 2014). Research studies (Ballantine, 2007; Kember, 2009; Anne et al., 2020) support the argument that generic skills develop through social, interactive, and collaborative forms of learning. According to Crebert et al. (2004), improving generic skills requires various group activities that promote collaboration and interaction among students.

The nature of chemistry education categorizes generic science skills into nine indicators: direct observation, indirect observation, understanding of scale, symbolic language, logical framework, logical inference, causal law, mathematical modeling, and concept building. It is important to note that these indicators should be presented objectively and without bias. Miliszewska's (2009) research explains that symbolic language skills, such as understanding chemical symbols, formulas, and equations, are essential for learning chemistry. Symbolic language is one of the three levels of representation in chemistry learning, along with macroscopic and microscopic. To improve students' science skills, it is necessary to train them in uniting the relationship between two variables in a chemical reaction and in solving problems. This requires them to associate concepts that have been previously learned as components of logical inference indicators.

Instrumental analysis chemistry is a branch of analytical chemistry that focuses on the use of special tools or instruments to analyze the composition and structure of chemical substances. Quantitative analysis methods are commonly used in laboratory research, industry, and other sciences to detect and quantify chemical compounds in various samples (Khopkar, 2003). Modern instruments are used to determine the quantity of the components that make up the analyte and produce numerical data with certain units. In this case, it is essential for students to comprehend the connection between the theoretical aspects of chemical concepts discussed in lectures and their practical applications in the laboratory (Soebagio et al., 2005; Sodiq et al., 2005).

Currently, there is a concern regarding the lack of proficiency in these generic skills among students. They often struggle with formulating conclusions based on the theory and results of instrument analysis in chemistry practicum. The logical inference skills of students need improvement through thinking activities to draw conclusions from the obtained data. For instance, students are not taught to acquire knowledge and develop their own concepts when studying the Lambert-Beer Law. This law states that if the absorbance value of a solution is not in compliance, it will affect the calibration curve, which will not be a straight line with a linearity value of $r \neq 0.9999$ or = 1 (Skoog & West, 1971; Morisan, 2016). Active learning can enhance thinking skills and aid in understanding the concepts of the Lambert-Beer Law. One effective approach is to use science generic skills indicators. Researchers have developed an innovative method that utilizes visualization to teach abstract chemical concepts (Harrison & Coll, 2008; Toprak et al., 2011). To comprehend chemistry concepts, students must develop collaboration skills and the ability to explain concepts clearly. This can help overcome learning difficulties (Suja, 2011; Ernia, 2020).

Another strategy for transferring information from teacher to student is through the use of visual aids such as graphs, diagrams, and tables. According to Huron et al. (2021), visualization helps externalize thoughts and facilitate memory and information processing. Abera et al. (2022) further explained that visualization techniques, when used with a problem-based learning approach, significantly improve student attitudes. Visualization-based active learning strategies can encourage students to think critically, dig for better information, trigger creative ideas, and develop collaborative skills. Teacher-created visualizations can be an effective pedagogical approach for teaching syntax, social systems, reaction principles, support systems, and instructional impact (Huron and M. Keck, 2022). According to Gutierrez (2014) and Hariharan (2014), visualization has a significant impact on learners' comprehension in the classroom compared to text-only content.

The Problem-Based Learning model is a suitable approach to encourage students to think critically and actively about real-world problems (Rusman, 2011). Problem-Based Learning (PBL) is a student-centered approach to learning that emphasizes critical thinking and independent learning. The purpose of PBL is to promote active learning and problem-solving skills (İnel & Balım, 2013; Komalasari, 2013). In PBL, students work in groups to solve real-world problems, integrating concepts and skills from various disciplines. According to Gurses et al. (2015), student learning outcomes and skills can be improved using PBL strategies.

2. Methods

This research employs the ADDIE development model, which comprises five steps: Analysis, Design, Development, Implementation, and Evaluation. Data collection was conducted using observation sheets to evaluate the quality of the VC-MER learning strategy and questionnaire sheets to gauge student responses to the VC-MER learning strategy. The response questionnaire was assessed qualitatively by categorizing the percentage of student responses into appropriate categories, as listed in Table 1 (Ratumanan, 2003).

Table 1. Student Response Criteria

Criteria (%)	Category
80,1-100	Very high
60,1-80,00	High
40,1-60,0	Medium
20,1-40,0	Low
0,0-20,0	Very low

3. Results and Discussion

3.1 Results

3.1.1 Practicality of VC-MER Learning Strategy

1. Limited trial

a) Strategy implementation at the visualization stage

Figure 1 lists the percentage of syntax implementation for each lesson in the lesson plan developed based on the VC-MER learning strategy in the limited trial. The visualization stage in learning activities 1-3 has a very high level of implementation, according to Figure 1. At this stage, observer-assessed lecturer activities are:

1) Lecturers organize students towards the problem through the visualization stage by showing videos through direct and indirect observation.
2) The lecturer distributes (LKM) while communicating learning objectives.
3) Individually, students are asked to compile a logical and systematic framework according to the rules/regularities of the phenomena shown.
4) Individually, students are asked to answer the questions in the MFI.

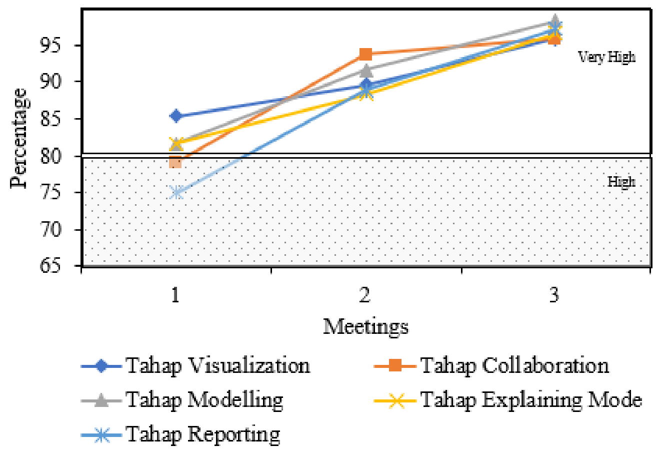

Figure 1: Percentage of Implementation of VC-MER Learning Strategy in the Limited Trial Class

According to the assessment results of three observers, the implementation of the visualization stage in the first learning activity was not optimal despite receiving a score of 85.4%. The observers noted that the lecturer's activities did not align with the lesson plan. The observer's assessment results indicate that the implementation of the visualization stage in the second and third learning activities went well, scoring 89.5% and 95.8%, respectively, according to the lesson plan.

b) Strategy implementation at the collaboration stage

The percentage of strategy implementation during the collaboration stage was high, with a rate of 71.9% in the first meeting and very high in the second (93.75%) and third (95.8%) meetings. During this stage, observers assessed the activities of the lecturer as follows:

5) Organize students into study groups.
6) Ask students to complete a learning task related to the problem formulated.
7) Collaboratively direct students to review and share findings that state the cause-and-effect relationship of a phenomenon.
8) Monitor student group work in group work and guide if students experience difficulties.

According to the observer's assessment, there is still room for improvement in organizing students into study groups, directing them to conduct studies collaboratively, and sharing findings that establish cause-and-effect relationships. This was noted during the collaboration stage of the first meeting. In accordance with the observer's feedback, the lecturer should prioritize organizing students into groups and guiding them in conducting research and sharing their findings during the next lesson. Following the lecturer's implementation of the observer's suggestions, the utilization of the collaboration stage strategy increased during the second and third learning activities.

c) Strategy implementation at the modeling stage

The percentage of strategy implementation during the modeling stage was high, with levels reaching 81.6%, 91.6%, and 98.3% at meetings 1-3, respectively. During this stage, observers assessed lecturer activities, which are:

9) Motivate and facilitate each group in completing a learning task.
10) Modeling successful work to work groups to complete a learning task.
11) Monitor students' active involvement in group discussions.
12) Lecturers provide guidance to assist students in the use of scales on objects observed based on data and literature studies.
13) Guiding qualitative or quantitative laws in science with symbolic language.

According to Figure 1, the first meeting revealed a need for improved monitoring of the provision of successful work examples to work groups in order to complete learning tasks. The lecturers should provide guidance to assist students in using scales to observe objects based on data and literature studies, as well as guidance on qualitative or quantitative laws in science using symbolic language. The observer's comments indicated that the activity of providing examples was still not specific enough. Furthermore, there was a shortage of instructors to guide students in using scales and explaining qualitative and quantitative laws. The inadequacies in the initial learning activities were addressed by enhancing the lecturer's involvement, resulting in an increase in the implementation of strategies during the collaboration stage in subsequent activities.

d) Strategy implementation at the explaining mode stage

The percentage of strategy implementation for the explaining mode stage has a very high level of implementation in the first to third meetings. Lecturer activities assessed by observers at this stage are:

14) Facilitate students in developing and presenting their work.
15) Ask each working group to present their work.
16) Reinforcing the results of student work.
17) Facilitate students in discussing their findings with other groups.
18) Ask students to convey obstacles in understanding the concept.

According to Figure 1, in the initial meeting, learning reached 81.6%. However, observers provided comments and suggestions indicating that improvements are still necessary. Specifically, the lecturers did not ask each work group to present their results. To address this issue, the lecturer should provide more opportunities and time for each work group to present their work. After the lecturers made improvements to the learning process, the implementation of the syntax for the explanatory stage increased by 88.3% and 96.6% in consecutive meetings.

e) Strategy implementation at the reporting stage

The percentage of strategy implementation for the reporting stage had a high level of implementation in the first meeting (75%) and a very high category in the second (88.8%) and third (97.2%) meetings. Lecturer activities assessed by observers at this stage are:

19) Lecturers evaluate students' works.
20) The lecturer confirms the results of the discussion.
21) Lecturers assign each group to summarize the results of the discussion in the form of a report.

According to Figure 1, the initial meeting achieved a 75% success rate. The observer noted that the lecturer did not fully evaluate the results of the student observations, failed to confirm the results of the group discussion, and did not assign the group to create a summary report. The observer's suggestions were implemented to address the shortcomings of the first meeting. Furthermore, the second and third stages have been improved, resulting in an 88.8% and 97.2% increase in the reporting stage at the next meeting. Overall, the observer's assessment of the learning strategy in the limited trial class showed that it met the criteria for the high category.

2. Broad trial

Figure 2 lists the percentage of syntax implementation in each lesson of the lesson plan developed based on the VC-MER learning strategy in the broad trial. The implementation of the VC-MER learning strategy syntax in the broad trial class has reached a very high category, ranging from 86.1% to 100%. This indicates that the improvements made in the limited trial class had a significant impact on the broad trial and overall improvement in the broad trial class.

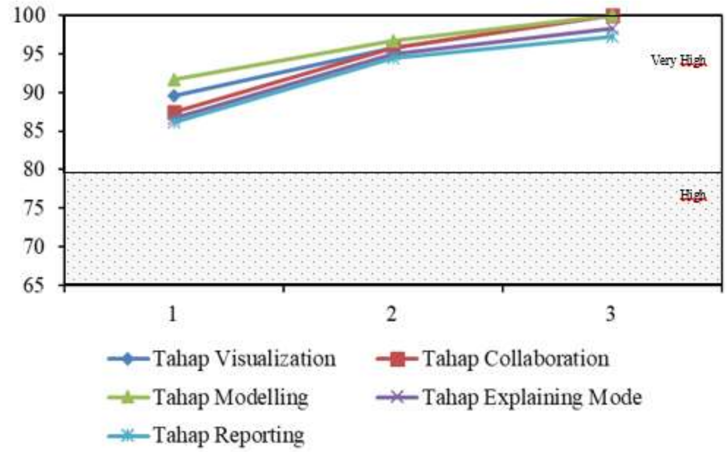

Figure 2: Percentage of Implementation of VC-MER Learning Strategy in the Extended Trial Classes

3.1.2 Effectiveness of VC-MER Learning Strategy

a) Analysis of generic science skills for limited trials

The effectiveness of the VC-MER learning strategy was evaluated by comparing pre-test and post-test scores, which were analyzed using N-Gain. Figure 3 shows the normalized N-Gain values for the limited trials.

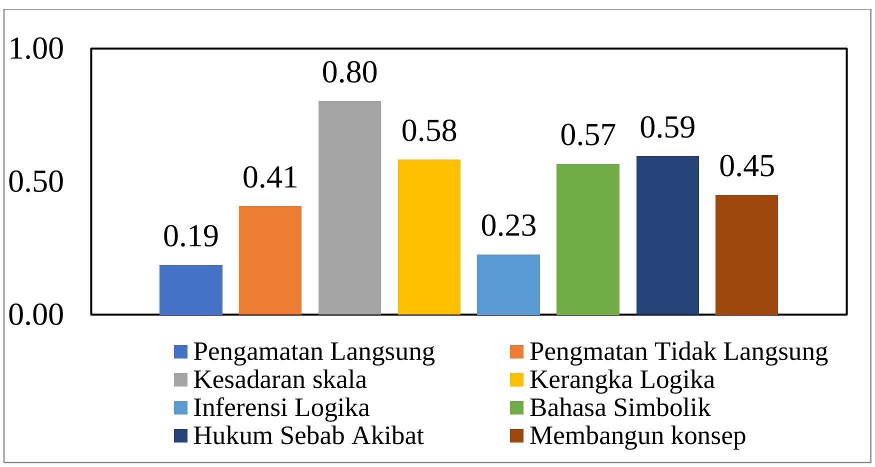

Figure 3: Limited Trial N-Gain Results

According to Figure 3, the N-Gain score shows an increase of 0.8 in KGS on the awareness scale indicator, categorized as high. The logical framework, symbolic language, the law of cause and effect, indirect observation, and concept-building indicators increased by 0.58, 0.57, 0.59, 0.41, and 0.45, respectively, categorized as medium. The direct observation and logical inference indicators increased by 0.19 and 0.23, respectively, categorized as low.

b) Analysis of generic science skills for large-scale trials

The effectiveness of the VC-MER learning strategy in large-scale trials was evaluated by comparing the pre-test and post-test scores of Pharmacy students in classes A and C. The scores were analyzed using N-Gain, and the normalized N-Gain values for extensive trials are presented in Figures 4 and 5.

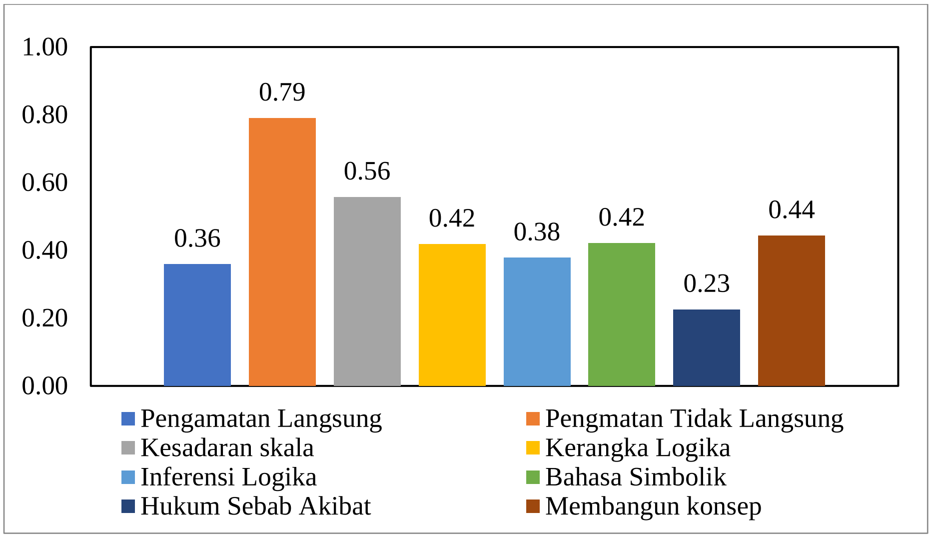

Figure 4. N-Gain Data for Large-Scale Trial of Class A Pharmacy Study Program

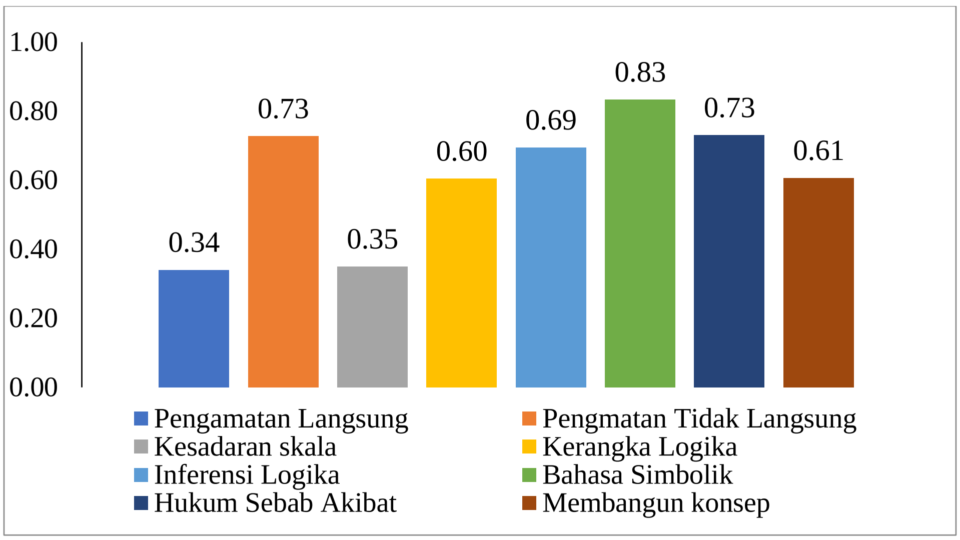

Figure 5. N-Gain Data for Large-Scale Trial of Class C Pharmacy Study Program

According to the N-Gain score, Pharmacy class A showed an increase in the indirect observation indicator to 0.79, categorized as high. The direct observation indicators for scale awareness, logical framework, logical inference, symbolic language, and concept building increased to the medium category with values of 0.35, 0.56, 0.42, 0.38, and 0.42, respectively. The causal law indicator, however, only increased by 0.23 and remained in the low category. In Pharmacy Class C, the indicators of indirect observation, symbolic language, and the law of cause and effect increased to the high category of 0.73, 0.83, and 0.73, respectively. The direct observation indicators, including scale awareness, logical framework, logical inference, and concept building, also increased, with an increase of 0.34, 0.35, 0.60, 0.69, and 0.61, respectively, falling into the moderate category.

c) Analysis of generic science skills for classroom implementation

The effectiveness of the VC-MER learning strategy was evaluated through extensive trials by comparing the pre-test and post-test scores of Pharmacy students in classes B and D. The normalized N-Gain values for the implementation classes are presented in Figures 6 and 7.

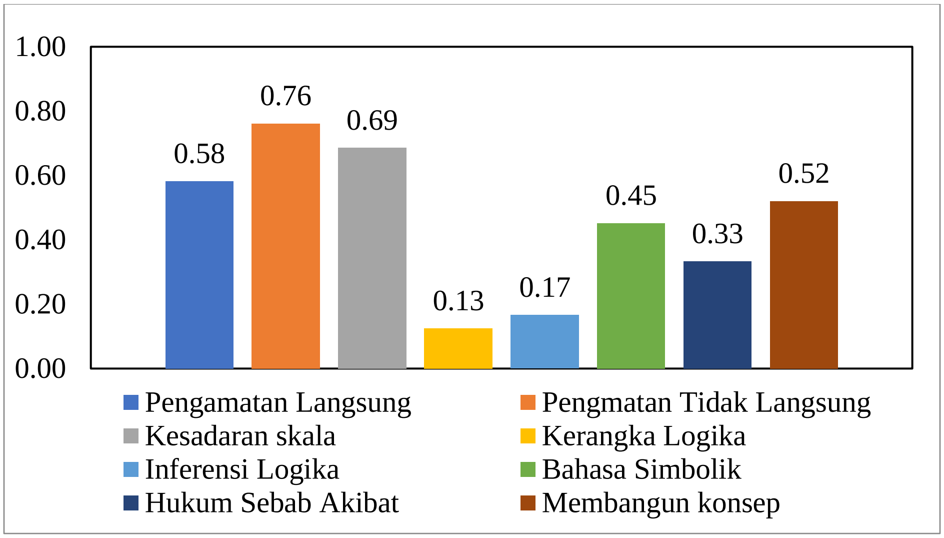

Figure 6. Normalized N-Gain Data for Class B Pharmacy Study Program

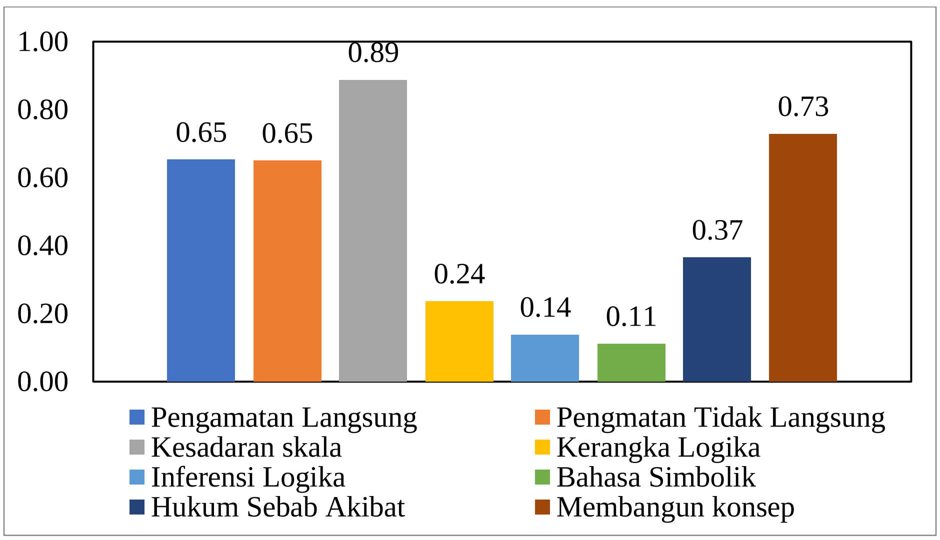

Figure 6. Normalized N-Gain Data for Class D Pharmacy Study Program

Figures 6 and 7 demonstrate an increase in KGS in both classes. In the Pharmacy B class, the indirect observation indicator showed a high increase of 0.76. The direct observation indicators, scale awareness, symbolic language, cause and effect law, and concept building, showed a moderate increase of 0.58, 0.69, 0.45, 0.33, and 0.52, respectively. The logic framework and logical inference indicators showed a low increase of 0.13 and 0.17, respectively. The consciousness scale indicator and concept development in Farmasi D experienced a significant increase of 0.89 and 0.73, respectively. The direct observation, indirect observation, and cause-and-effect law indicators also experienced an increase of 0.65, 0.65, and 0.37, respectively, falling under the moderate increase category.

3.2 Discussion

The results of the limited trial on one class of Chemistry Education Study Program students (Figure 1) indicate that the generic skills observed only reached a moderate level of achievement. Even for indicators of direct observation and logical inference, the achievement level was low, at 0.19 and 0.23, respectively. However, the awareness indicator achieved a high level of 0.8. Awareness of scale refers to a student's attitude and ability to comprehend sizes that are not typically encountered in everyday life, such as the size of molecules and electrons (Liliasari, 2007).

According to Brotosiswojo's categories, direct and indirect observation are considered easy to master generic skills. Additionally, the logical inference indicator is used to help students develop the ability to explain phenomena as a logical result of existing conclusions or theories. The text also discusses the relationship between concentration, absorbance, and the Lambert-Beer Law in UV-Vis Spectrophotometry. Logical inference is the ability to draw new conclusions as a logical consequence of previous laws without conducting new experiments. However, the N-Gain value of 0.23 for the logical inference indicator indicates that students' scientific generic skills in drawing new conclusions as a logical result of previous laws without conducting new experiments still need improvement. This finding supports Brotosiswojo's (2001) assertion that developing the generic skill of logical inference is challenging. Logical inference can be improved through thinking activities that involve concluding given data or examples. In the context of science process development, inference refers to the activity of deducing from given data or premises to another example. In scientific development, inference is the act of deducing one example from given data or premises.

The analysis of N-Gain values shows that the N-Gain values for classes A and C are high, ranging from 0.73 to 0.79. This indicates that the VC-MER strategy in PBL syntax, specifically in the problem orientation phase with visualization learning strategy, enables students to design and predict, thus enhancing their generic skills in indirect observation related to experimental data and cognitive domain indicators. The other N-Gain values, namely direct observation indicators, scale awareness, logical framework, logical inference, symbolic language, and concept building, experienced an average increase in the moderate category, respectively, at 0.3589, 0.5571, 0.4183, 0.3778, 0.42, and 0.44. Meanwhile, the cause-and-effect indicator increased by 22.56%, falling under the low category. Unlike class C pharmacy, what is interesting about class A pharmacy is that the cause-and-effect indicator has increased significantly by 0.73. As for the direct observation indicator, scale awareness, logical framework, logical inference, and concept building, both class A and C pharmacies have experienced a moderate increase of 0.34-0.6. It is interesting to note that the symbolic language indicator for class C shows a higher N-Gain value compared to class A, with a difference of up to 50%, namely 0.83 and 0.42. This is in line with the activities in the LKM developed by the researcher, which contains science generic skills that guide students in understanding chemical symbols. Based on the N-Gain value obtained for indirect observation indicators in the high category, namely 0.73-0. The study shows that students in classes A and C possess generic science skills in observing phenomena, both directly and indirectly, and in constructing logical and systematic frameworks according to rules and patterns.

The analysis of KGS indicators for the implementation classes, namely classes B and D of the Pharmacy Study Program, shows an improvement in the logical framework and logical inference indicators, with very low categories for both classes. In class B, the categories are 0.13 and 0.17, while in class D, they are 0.24 and 0.14. To improve this indicator, the researcher has designed the VC-MER strategy, which presents interactive stages, especially visualization and collaboration, as well as an explaining mode where students are trained to make logical predictions to solve problems or draw conclusions from a problem. These skills will produce students who can understand concepts and teach problem-solving strategies (Tricot & Sweller, 2014). In response to this, the VC-MER learning strategy designed by the researcher presents interactive stages to improve these indicators. These can be trained through activities such as concluding thoughts, discovering concepts, and connecting concepts to form a comprehensive understanding of the data, even though logical inference places difficult-to-develop abilities (Lawson, 1998). The development of generic skills in logical framing and cause-and-effect relationships through the concept of analytical chemistry instruments is indicated by low or moderate N-gain. These relationships have not been well-mastered by prospective chemistry teachers. This includes relationships such as the correlation between compound absorbance and concentration, as well as the correlation between potential and electrical conductivity with concentration.

4. Conclusions

The objective of this research is to develop a VC-MER learning strategy based on Problem-Based Learning that can enhance students' generic science skills. The trial results suggest that the VC-MER learning strategy based on Problem-Based Learning is highly effective in improving students' generic science skills, as demonstrated by the N-Gain analysis for each class. The N-Gain values for the limited trial class, wide trial class A, and wide trial class C were 47.71%, 45.72%, and 67.32%, respectively. For the implementation of the Pharmacy Study Program, Class B and Class D achieved an average N-Gain value of 60.65% and 56.4%, respectively. All classes attained an N-Gain between 30% and 70%, placing them in the 'moderate' category according to the N-Gain criteria. The research adopted several indicators of generic science skills in students, and the majority of them experienced an increase in the moderate category. However, the VC-MER learning strategy has not yet incorporated all indicators of generic science skills. Therefore, there are still several important generic skills that students need to improve but are not being addressed. The VC-MER learning strategy was recently tested on the concepts of Spectroscopic Engineering, UV-Vis Instruments, and AAS Instruments. It is hoped that this strategy can be applied to other courses.

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