RESEARCH ARTICLE

Students' inquiry skills progression based on STEM approach and inquiry lab

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Abstract: Inquiry skills are one of the skills that students need to master in learning biological concepts. Inquiry skills are influenced by many factors, one of which is the lesson plan. This study aims to examine the effect of inquiry lab and STEM models on inquiry skills progression. The research design used was a quasi-experiment non-randomized control group, pretest-posttest design, with three treatments, namely discovery learning lesson plan as control (C), inquiry lab lesson plan (E1) and STEM lesson plan (E2) as treatment. The three classes were randomly selected from six classes XI of Science. All students in the selected class became the research sample (N = 98), with details. The control class consisted of 33 students, E1 32 students, and E2 33 students. The material taught in all classes is the human respiratory system. Data in inquiry skills progression is measured before and after treatment. The instrument takes the form of an essay test. Data analysis using ANCOVA (p = 0.05%). The results showed that the inquiry lab and STEM models had a significant effect, and the inquiry lab model had the best effect.

Keywords: Inquiry lab; inquiry skills; learning progression; lesson plan; respiratory system; STEM

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Article history:
Received: 4 April 2023
Revised: 25 July 2023
Accepted: 26 July 2023
Published: 30 July 2023

10.24057/jpbi.v9i2.25698

p-ISSN: 2442-3750
e-ISSN: 2537-6204

How to cite:
Chaerunisa, Z.F., Ramli, M., & Sugiharto, B. (2023). Students' inquiry skills progression based on STEM approach and inquiry lab. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *9*(2), 206-216. https://doi.org/10.22219/jpbi.v9i2.25698

Introduction

Inquiry skills are necessary to study and understand the practice of scientists in scientific investigations. Investigations in inquiry are carried out according to scientific procedures that refer to the way scientists work. In their work, scientists always take scientific steps in the inquiry process. Inquiry-based learning is believed to be able to develop students' knowledge and skills. Inquiry skills refer to seven skills consisting of problem identification, formulation of research questions; formulating hypotheses, planning experiments, conducting experiments; analysis and interpretation of results; and drawing conclusions and presenting findings (Pedaste et al., 2012). The entire series of stages is simultaneous and continuous, meaning that the first stage must be achieved before moving on to the next stage.

The results of the 2018 Program for International Student Assessment (PISA) show that student achievement in science in Indonesia is classified as low, ranking 73 out of 78 countries with an average score of 396 points, while the OECD average score is 489 points (OECD, 2019). However, in the last 10 years, there has been an increase in the scores of Indonesian students which are close to the OECD average scores in each period (OECD, 2016, 2018; Organization for Economic Cooperation Development, 2015). The results of the assessment show two things. On the one hand, it shows that there are factors that cause the low science skills of students in Indonesia. On the other hand, there is potential for developing students' science skills. Purwati et al., (2021) stated that the causes of students' low science skills include science learning which still tends to be textual and less contextual. In addition, abstract science content is often difficult for students to understand. Therefore, the low science ability of students in Indonesia based on the results of PISA allegedly indicates that students' inquiry abilities are still relatively low.

Tabun et al., (2019) stated that one of the causes of students' low science skills was not mastering one or several scientific stages such as students not being able to formulate hypotheses. This then causes students to have difficulty in mastering other stages of science skills. Furthermore, students find it difficult to formulate problems to find the best solutions independently (Ganajová et al., 2021).

The results of early observations of Biology learning at Senior High School 2 of Pringsewu Lampung show that all teachers who teach using the discovery learning model have not optimally accommodated the inquiry process. The teacher has implemented a mixture of lectures, discussions, and practicum. However, the practicum given by the teacher did not lead students to achieve inquiry skills. The teacher usually gives a student worksheet that contains all the completeness and practicum procedures, so that students then only follow the steps on the worksheet. There are no independent inquiry skills training initiatives. On the other hand, the learning media used so far are Biology textbooks from schools, PowerPoint slides, and videos.

Furthermore, preliminary research data strengthens existing assumptions. Based on the 30 students identified, all of them had low inquiry skills. This result is seen from the percentage score at the problem identification stage of 38.33%; stages of preparation of research questions of 36.67%; the hypothesis formulation stage of 29.17%; trial planning stage of 30.38%; the stage of conducting an experiment of 38.33%; stages of analyzing and interpreting results 37.50%; and the closing stage of 35.83%. The test results show that the performance of inquiry skills is not optimal. Students' soft inquiry skills are thought to be caused by: 1) learning environment and topics, namely teaching materials, visual representations, unplanned inquiry activities, abstract and complex topics; 2) problems related to teachers, namely knowledge givers and not facilitators; 3) problems related to students, namely passive, boring, confusing (Lubiano & Magpantay, 2021).

Improvement of learning methods, strategies, approaches, and types of activities in learning can help improve inquiry skills in biology learning. Another option is to implement continuous training based on learning progress (LP). A way of reasoning from a basic concept to a complicated understanding of a concept is indicated as one of the most fundamental things in teaching inquiry (National Research Council, 2007). LP in science is also defined as an empirically based and testable hypothesis about how students understand and their ability to use scientific core concepts, explanations, and scientific practice that continues to evolve with appropriate learning (Corcoran et al., 2009). However, LP does not only describe students' thinking but also reflects the sequence of skill acquisition or skill level that students can achieve based on their age. The application of LP to empower skills has been studied in various studies, namely argumentation (Henderson et al., 2014; Osborne et al., 2016; Song et al., 2023).

The fulfillment of each stage of inquiry skills based on LP can be achieved through a good lesson plan. The lesson plan is used as a reference in achieving learning targets, namely inquiry skills. Lesson plans that can accommodate inquiry skills are those in which there are stages of inquiry. Among others, lesson plans with inquiry labs and STEM learning models (Baharin et al., 2018; Baur & Emden, 2020; Newton & Tonelli, 2020). Lesson Plan is a procedure for learning activities from the beginning to the end of learning, which is a scenario or guideline for teachers to implement class activities (Moonsri & Pattanajak, 2013; Purnamasari & Sukanto, 2016; Anggraeni & Akbar, 2018). Teacher preparation in lesson plans is important to determine teaching objectives, consider available resources, and appropriately design activities (Lee & Takahashi, 2011). Lesson plans can also help predict learning outcomes or targets (Mustafa et al., 2021).

Learning models that are thought to increase inquiry skills are learning models developed based on experiential learning theory, which emphasizes acquiring knowledge and skills through learning experiences, and contextual learning, which emphasizes contextual and real learning (Nilasari et al., 2016). These models include: inquiry lab and STEM. Inquiry labs are important to a student's science experience (Demircioglu & Ucar, 2015). Perdana et al. (2018) was stated that the inquiry lab is one of the learning models that can overcome abstract and complex things. Inquiry-based lab learning emphasizes activities to help students learn and understand the process and skills of thinking like scientists and the characteristics of scientific research (Pranoto et al., 2017). Inquiry lab learning focuses on experimental activities. Experimental activities are part of implementing the scientific method to compare prediction results with theory, and several scientific skills are trained in experimental activities. In addition, students are also trained to interpret scientific data and evidence based on the results of experiments conducted at the inquiry lab stage (Arief & Utari, 2015). Inquiry labs can also make students bridge the gap between theory and practice, increase enthusiasm, encourage scientific attitudes, and develop observation, reasoning, and critical thinking skills. In addition, inquiry labs can improve knowledge competence (cognitive) and skills (psychomotor) (Pranoto et al., 2017). In line with the research of Sulawanti et al., (2019), the laboratory-based inquiry learning model has a positive influence on student learning because, in the process, students are invited to work like a scientist, providing students with scientific experiences, making it easier for students to understand the material and can improve students' psychomotor skills. The inquiry lab learning model provides opportunities for students to better understand the learning material because students can directly see a material concept with scientific evidence, making it easy to understand and remember (Marleni & Sahono, 2019).

STEM approach learning integrates science, technology, engineering, and mathematics learning which is recommended for to practice of 21st-century skills (Sakdiah et al., 2020). STEM is also the design of learning activities that raise real issues as a means of training to solve problems in everyday life through a problem-solving process-based design used by engineers and scientists with an interdisciplinary approach (Budhi & Fawaida, 2021).

These two learning designs, inquiry lab and STEM, are thought to affect students' inquiry skills. But based on previous research, which model works more effectively has not been proven. Therefore, it is necessary to test the influence of the two learning models by comparing their influence with the lesson plan commonly used by teachers, namely the discovery learning lesson plan. The formulation of the problem in this study is whether there is an influence of lesson plan inquiry lab and STEM on inquiry skills progression? The purpose of this study was to determine the effect of lesson plan inquiry lab and STEM on inquiry skills progression. The research carried out can provide an overview to teachers regarding the lesson plan inquiry lab and STEM on inquiry skills progression, so that teachers can apply a learning activity that can improve students' inquiry skills in biology learning.

Method

Research design and population of the study

This research uses quasi-experimental methods. The research design used was a non-randomized control group, pretest-posttest design (Ary et al., 2010). The independent variables in this study were three kind of lesson plan refers to discovery learning, inquiry lab, and STEM. The study population was all grade XI students of SHS 2 of Pringsewu, Lampung Province, Indonesia (N = 276), and divided into nine classes.

Sample and sampling technique

The research sample was students in three classes used in the study totaling 98 persons. The three classes were selected from six classes XI of science with a random sampling technique. This study used three samples totaling (N = 98), with class details consisting of 33 students (C class) as a discovery learning control class, 32 students of E1 class as inquiry lab treatment, and 33 students of E2 class as STEM a treatment. Both of E1 and E2 are a treatment class of this research.

Instrument for data collection

This research uses instruments: lesson plan of inquiry lab, lesson plan of STEM, initial observation questionnaire, and inquiry skills test. The lesson plan inquiry lab is structured based on the syntax of 1) observation; 2) manipulation; 3) generalization; 4) verification; 6) application (Wenning, 2011). STEM lesson plans are structured based on the syntax of 1) identify and define problems; 2) research the need or problem; 3) develop possible solutions; 4) select the best possible solutions; 5) construct a prototype 6) test and evaluate the solutions; 7) communicate the solution; 8) redesign; 9) completion (Hynes et al., 2011). A comparison of the characteristics of inquiry lab, STEM, and discovery learning models can be seen in Table 1. The syntax description of the lesson plan of the inquiry skills stage adopted from Pedaste can be seen in Table 2. The open-ended questionnaire was given to biology subject teachers at SHS 2 of Pringsewu to obtain learning information in class. The written test is an open-ended question that refers to the stages of inquiry skills proposed by Pedaste et al. (2012). Tests in the form of pretests are carried out before starting learning, and posttests are carried out after completing learning using the application of lesson plans with inquiry lab models, and STEM respiratory system materials. Written tests in the form of pretests and posttests are conducted to measure inquiry skills based on student learning progression.

Table 1. Comparison of learning model characteristics of inquiry lab, STEM, and discovery learning

Comparison Indicators	Experiment Group		Control Group
	Inquiry Lab	STEM	Discovery Learning
Syntax	1. Observation 2. Manipulation 3. Generalization 4. Verification 5. Application	1. Identify and define problems 2. Research the need or problems 3. Develop possible solutions 4. Select the best possible solutions 5. Construct a prototype 6. Test and evaluate the solutions 7. Communicate the solution 8. Redesign 9. Completion	1. Stimulation 2. Problem statements 3. Data collection 4. Data processing 5. Verification 6. Generalization

Table 2. Description of lesson plan syntax

Lesson plan	Syntax	1	2	3	4	5	6	7
Inquiry Lab	Observation	✓	✓					
	Manipulation			✓	✓			
	Generalization					✓		
	Verification						✓	
	Application							✓
STEM	Identify and define problems	✓						
	Research the need or problems		✓	✓				
	Develop possible solutions				✓			
	Select the Best Possible Solutions						✓	
	Construct a prototype					✓		
	Test and Evaluate the Solutions							
	Communicate the Solution							✓
	Redesign							
	Completion							
Discovery Learning	Stimulation	✓						
	Problem statements	✓						
	Data collection		✓					
	Data Processing						✓	
	Verification						✓	
	Generalization							✓

Information: 1 = Identify the problem; 2 = Formulate research questions; 3 = Formulating hypotheses; 4 = Plan an experiment; 5 = Experiment; 6 = Analyze and interpret results; and 7 = Drawing conclusions

Validation and reliability instrument

The lesson plan developed has been tested for feasibility. Feasibility test lesson plan inquiry lab and STEM in the form of validation from learning instrument experts using one expert validator who is a lecturer at the University of Lampung in the field of expertise in biology education. The purpose of validating the results of lesson plan development is to obtain input and suggestions for improvement until the lesson plan is declared feasible and can be used as a research instrument. The feasibility test of the lesson plan consists of six aspects, namely the formulation of indicators, learning objectives, learning materials, selection of learning resources and teaching media, assessment of learning outcomes, and aspects of inquiry skills. Lab and STEM lesson plans, and inquiry, are declared feasible for use, with some improvements that researchers need to make. The learning progression-based inquiry skill written test instrument developed was validated by question development experts using two expert validators. The first expert validator was a lecturer at Sebelas Maret University in animal structure expertise, and the second expert validation was a lecturer at the University of Lampung in the field of biology expertise. Next, it was tested on students and analyzed for feasibility using RASCH analysis. The validity of the questions shows that the analysis results of the question items from the seven inquiry skills question items meet three conditions. It can be stated that each question item has good quality and can be used to measure students' inquiry skills. The questions have been tested for reliability and declared feasible and reliable.

Experimental procedure

Three classes are used to determine the effect of the independent variable on the dependent variable. The experimental group used two classes, while the control group used one. The first class applied an inquiry lab model of respiratory system material to inquiry skills based on the learning progression. The second class applied a STEM model of respiratory system material to inquiry skills based on the learning progression. The third grade was given an application using the discovery learning model of respiratory system material commonly used by teachers. Furthermore, the three classes were given a pretest and a posttest. The design structure of the non-randomized control group, pretest-posttest design, is presented in Table 3.

Table 3. Non-randomized control group, pretest-posttest design

Class	Pretest	Independent variable	Posttest
E1	Y1	X1	Y2
E2	Y1	X2	Y2
C	Y1	-	Y2

Information: E = Experiment; C = Control; Y1 = Inquiry skills before treatment; Y2 = Inquiry skills after treatment; X1= Treatment of Lesson Plan inquiry lab respiratory system material on inquiry skills based on learning progression; and X2 = Treatment of STEM Lesson Plan respiration system material on inquiry skills based on learning progression.

Data analyses

Inquiry skills value data were statistically tested using ANCOVA or covariance analysis. Covariance analysis was used to test the difference in treatment of a group of posttest result data after adjusting for the covariate effect, namely the pretest. Further tests using the LSD test were conducted to recommend the best treatment that affects inquiry skills. The ANCOVA test and LSD test in this study used SPSS software version 16 for Windows. The ANCOVA test assumes that the data is normally distributed and has a homogeneous variance. The ANCOVA test can be performed after prerequisite tests, namely the normality and homogeneity tests.

Results and Discussion

The effect of using inquiry lab and STEM models on inquiry skills

The normality test in the study used the Shapiro-Wilk test because the study sample was less than 100 (González-Estrada & Cosmes, 2019). The results of the normality test with SPSS 16 on the pretest and post-test inquiry skills values showed that the three groups used in the study had a significance value of >0.05, which means H0 was accepted so that the samples used in the study were declared normally distributed (Suryadi et al., 2018). The normality test results of the three groups can be seen in Table 4.

Table. 4 Normality test results

Classes		Shapiro-Wilk		
		Statistic	Df	Sig.
Pretest	Control	.970	33	.477
	Inquiry Lab	.966	32	.387
	STEM	.965	33	.355
Posttest	Control	.965	33	.366
	Inquiry Lab	.949	32	.137
	STEM	.963	33	.226

Based on the homogeneity test analysis using Levene's test of equality of error variance test with SPSS 16 on the pretest and posttest inquiry skills values, it was found that the significance value >0.05, which means H0 was accepted, so that the samples used in the study had homogeneous variances (Suryadi et al., 2018). The homogeneity test results can be seen in Table 5.

Table 5. Homogeneity test results

F	df1	df2	Sig.
.138	2	95	.871

The ANCOVA test results showed a significance value of <0.05, so H0 was rejected (Hidayat, 2018). ANCOVA test results can be seen in Table 6.

Table 6. ANCOVA test results

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4412.193a	3	1470.731	21.418	.000
Intercept	13417.591	1	13417.591	195.400	.000
Pretest (covariate)	.281	1	.281	.004	.949
Treatment (model)	4406.223	2	2203.112	32.084	.000
Error	6454.716	94	68.667		
Total	547959.000	98			
Corrected Total	10866.908	97			

Based on the results of the ANCOVA test, the treatment of the learning model has a significance of 0.000 which means that H0 is rejected, so there is a difference in the results of students' inquiry skills scores due to treatment. Meanwhile, the pretest covariate showed a nominal value of 0.949, meaning there is no difference in students' initial ability (pretest), which influences the results of applying the learning model. The inquiry lab is the model that has a major influence on students' inquiry skills. This can be seen in the results of advanced tests Table 7.

Table 7. Advanced test results

Treatment (I)	Class (J)	Average Difference (I-J)	Sig.
Discovery learning	Inquiry lab	-16.445*	.000
	STEM	-7.182*	.001
Inquiry lab	Discovery learning	16.445*	.000
	STEM	9.263*	.000
STEM	Discovery learning	7.182*	.001
	Inquiry lab	-9.263*	.000

Based on the results of the LSD advanced test, it can be grouped based on the LSD notation obtained from the Tukey test analysis. LSD notation can be seen in Table 8.

Table 8. Notation of LSD test results

Treatment	Average	Notation		
Discovery learning	66.24	a		
STEM	73.42		b	
Inquiry lab	82.69			c

The smallest real difference notation results show that the discovery learning model has the lowest average among other models, which is 66.24. This shows that the discovery learning model differs from the STEM and inquiry lab models. The STEM model can be seen as an average of 73.42, with a different notation from the discovery learning and inquiry lab models. The inquiry lab model has the highest average score of 82.69, and the notation differs from the STEM and discovery learning models. Therefore, the inquiry lab model has the best results in empowering students' inquiry skills compared to the discovery or STEM models. Based on this, it can be concluded that there are significant differences between the three models with different treatments.

Based on the ANCOVA test analysis results, there were significant differences in students' inquiry skills scores in the three treatments. The significant difference is evidenced by the results of the ANCOVA test with a significance value (<0.05). Lesson plans developed in both inquiry labs and STEM models have significant value. This following previous research that inquiry lab and STEM learning models can improve students' inquiry skills (Baur & Emden, 2021; Çetİn, 2021; Erwanto, 2018; Hasanah et al., 2017; Hofstein & Lunetta, 2004; Ozturk, 2021; Newton & Tonelli, 2020; Sofiani et al., 2018; Yilmaz & Yanarates, 2022). However, based on the results of further test analysis, the inquiry lab model has a more significant influence than other learning models.

Lesson plan with inquiry lab learning model has the ultimate goal of achieving each stage in inquiry skills by conducting investigation and experiment activities (Pedaste et al., 2015). The application of the inquiry lab learning model provides an opportunity for students to better understand the learning material because students can see directly a material concept with scientific evidence, making it easy for students to understand and retention (Marleni & Sahono, 2019).

The stages in the inquiry lab model accommodate students to achieve inquiry skills. The observation stage in the inquiry lab can accommodate students' ability to identify problems as aspects of inquiry skills (Pedaste et al., 2015). In addition, the observation stage can achieve problem formulation in inquiry skills (Kremer et al., 2013). Problem identification is made by observing phenomena or problems occurring, describing in detail, until students can compile a problem formulation to be studied. Furthermore, the students can train students to formulate hypotheses in inquiry skills (Saputra et al., 2019). In addition, the manipulation stage can also accommodate inquiry skills, namely planning experiments (Septi & Shofiyah, 2020). The hypothesis was formed after planning the study (Orosz et al., 2022). The research design prepared by students is obtained through discussion activities between students and the determination of methods, tools, and materials to be used in research.

Generalizations made by students in learning with the inquiry lab model can empower inquiry skills through experimental activities. Students carry out the experiment by constructing the knowledge they already have to prove the experimental plan that was prepared at the manipulation stage (Safaah et al., 2017). Furthermore, the verification stage of the inquiry lab can accommodate students in analyzing and interpreting results (Febri et al., 2020). After conducting experiments, students must be able to analyze and interpret experimental results to determine whether the results obtained are in accordance with the hypotheses that have been made (Wen et al., 2020). At this stage, systematically, students will draw conclusions from the experimental data they have and relate them to concepts and provide strong arguments on the data. Furthermore, these activities can train students to not only read data but also interpret what is meant behind the data so that it is easier for others to understand. These results have shown that the inquiry laboratory can train students' inquiry skills.

On the other hand, learning using the STEM model can actually train students' inquiry skills. This is in line with (Scherer et al, 2019; Rohman et al, 2022) which state that STEM can train students to sharpen logic in finding solutions to problem-solving in the best way. Several stages in the STEM lesson plans can accommodate inquiry skills, starting from the stages of identifying and defining problems to product evaluation. Problem identification activities put students in situations where they can use their potential inquiry skills to determine what problems are around them (Priemer et al., 2020). Several studies state that when this activity is carried out consistently it can help students to improve and elaborate on these inquiry skills in their daily lives.

Furthermore, these problem-identification skills can accommodate students to continue to carry out in-depth investigations to formulate problems and propose hypotheses. Problem formulation is done by students to understand and consider various factors when solving problems. In this case, students need to explore challenges to get good information in solving problems (Zhbanova, 2017). The formulation of a hypothesis is a student's systematic effort that is carried out in accordance with the formulation of the problem that has been identified, the variables involved in it, and determines the relationship between related variables (Awalin & Ismono, 2021). Some researchers believe that, in this activity, students have also developed possible solutions that can be proposed. It is believed that these series of activities can accommodate inquiry abilities in designing and planning experiments. Experiments were planned independently through group discussions and brainstorming activities (Baran et al., 2016).

Students can choose the best solution after they have tested the hypothesis through the experiments that have been done. According to some experts, at this experimental stage students' inquiry skills were accommodated through data analysis activities and interpretation of the results obtained. Furthermore, this stage provides space for students to answer accompanying questions on the data that has been obtained such as what are the results and what is the meaning behind the data. This activity revives the reasoning space for students to answer these questions (Dasgupta et al., 2019). The answers they get will eventually be used as a basis for choosing the best solution (Wells, 2016). Furthermore, at the construction stage, prototypes can accommodate students' inquiry skills in experiments by preparing a solution model, and students must try the model repeatedly (Sutaphan & Yuenyong, 2019). The final stage of STEM lesson plans, communicating solutions, can accommodate students' inquiry skills in concluding documentation activities and presenting results (Prodromou & Lavicza, 2018).

The stages of the STEM lesson plans that have not been able to accommodate students' inquiry skills are the test and evaluation of solutions by evaluating the products produced in the form of objects, the redesign stage by product redesign activities, and competition with finished products as product decision-making activities. These stages do not lead to fulfilling aspects of inquiry skills but innovative skills and creative thinking skills that produce a product (Carbonell-Carrera et al., 2019; Jawad et al., 2021). This is reinforced by Aguilera & Ortiz-Revilla, (2021) which states that based on the results of a systematic study, seven STEM models can train student creativity. Although in general the stages of STEM learning can accommodate students' inquiry skills through the characteristics embedded in the STEM model. However, the ultimate goal of STEM learning is not the attainment of stages in inquiry skills but products based on science, mathematics, and technology (Suprapto, 2016).

Conclusion

Based on the description above, lesson plans developed with lab and STEM-based learning progression inquiry skills models have proven effective. The inquiry lab learning model on respiratory system material has a better effect on inquiry skills than the STEM model. This is evidenced by the results of the ANCOVA and further tests, which state that the inquiry lab has a higher average value than others. This study has the disadvantage that testing is limited to one class per treatment. Suggestions for further research are needed to develop similar lesson plans on materials other than the respiratory system to check the effectiveness of STEM learning models and inquiry labs.

Acknowledgement

A part of this research was financed through National Research Agency of Indonesia/*Badan Riset Nasional* (BRIN) Grants with contract numbers 221.1/UN27.22/HK.07.00/20211 by the LPPM University of Sebelas Maret year 2021/2022.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contributions

Z. F. Chaerunisa: collecting data and writing article; **M. Ramli:** research directing, review, editing article and donation; and **B. Sugiharto:** review and editing article.

References

Aguilera, D., & Ortiz-Revilla, J. (2021). STEM vs. STEAM education and student creativity: A systematic literature review. *Education Sciences*, *11*(7), 1–14. https://doi.org/10.3390/educsci11070331

Anggraeni, P., & Akbar, A. (2018). Kesesuaian rencana pelaksanaan pembelajaran dan proses pembelajaran. *Jurnal Pesona Dasar*, *6*(2), 55–65. https://doi.org/10.24815/pear.v6i2.12197

Apanasionok, M. M., Hastings, R. P., Grindle, C. F., Watkins, R. C., & Paris, A. (2019). Teaching science skills and knowledge to students with developmental disabilities: A systematic review. *Journal of Research in Science Teaching*, *56*(7), 847–880. https://doi.org/10.1002/tea.21531

Arief, M. K., & Utari, S. (2015). Implementation of levels of inquiry on science learning to improve junior high school student's scientific literacy. *Indonesian Journal of Physics Education*, *11*(2), 117–125. https://doi.org/10.15294/jpfi.v11i2.4233

Ary, D., Jacobs, L. C., Sorensen, C., & Razavieh, A. (2010). *Introduction to research in education (8th ed.)*. Cangage Learning. Canada. http://www.modares.ac.ir/uploads/Agr.Oth.Lib.12.pdf.

Awalin, N. A., & Ismono. (2021). Integrative science education and teaching activity journal the implementation of problem based learning model with STEM (science, technology, engineering, mathematics) approach to train students' science process skills of XI Graders on chemical equilibrium topic. *INSECTA*, *2*(1), 1–14. https://doi.org/10.21154/insecta.v1i2.2496.

Baharin, N., Kamarudin, N., & Manaf, U. K. A. (2018). Integrating STEM education approach in enhancing higher order thinking skills. *International Journal of Academic Research in Business and Social Sciences*, *8*(7), 810–821. https://doi.org/10.6007/ijarbss/v8-i7/4421

Baran, E., Canbazoglu Bilici, S., & Mesutoglu, C. (2016). Moving STEM beyond schools: Students' perceptions about an out-of-school STEM education program. *International Journal of Education in Mathematics, Science and Technology*, *4*(1), 9. https://doi.org/10.18404/ijemst.71338

Baur, A., & Emden, M. (2020). How to open inquiry teaching? An alternative teaching scaffold to foster students' inquiry skills. *Chemistry Teacher International*, *3*(1), 1–12. https://doi.org/10.1515/cti-201 9-0013

Budhi, H. S., & Fawaida, U. (2021). Pengembangan perangkat dan model pembelajaran berbasis proyek mata kuliah IPA terpadu melalui pendekatan STEM (science, technology, engineering and mathematics. *Jurnal Ilmiah Edukasia (JIE)*, *1*(1), 99–112. https://journal.upgris.ac.id/index.php/JIE/ article/view/7969.

Capps, D. K., Crawford, B. A., & Constas, M. A. (2012). A review of empirical literature on inquiry professional development: alignment with best practices and a critique of the findings. *Journal of Science Teacher Education*, *23*(3), 291–318. https://doi.org/10.1007/s10972-012-9275-2

Carbonell-Carrera, C., Saorin, J., Melian-Diaz, D., & de la Torre-Cantero, J. (2019). Enhancing creative thinking in STEM with 3D CAD modelling. *Sustainability*, *11*(21), 6036. https://doi.org/10.3390/su 11216036

Çetİn, A. (2021). The effects of STEM applications on pre-service elementary teachers ' stem awareness, self-efficacy and inquiry skills. *E-International Journal of Educational Research*, *12*(5), 160–176. https://doi.org/10.19160/e-ijer.986545

Corcoran, T., Mosher, F. A., & Rogat, A. (2009). *Learning progressions in science: An Evidence-based approach to reform*. Consortium for Policy Research in Education (CPRE). https://eric.ed.gov/?id= ED506730.

Dasgupta, C., Magana, A. J., & Vieira, C. (2019). Investigating the affordances of a CAD enabled learning environment for promoting integrated STEM learning. *Computers and Education*, 122–142. https://doi.org/10.1016/j.compedu.2018.10.014

Demircioglu, T., & Ucar, S. (2015). Investigating the effect of argument-driven inquiry in laboratory instruction. *Educational Science: Theory & Practice*, *15*(1), 267–283. https://doi.org/10.12738 /estp.2015.1.2324

Erwanto, D. (2018). Guided-inquiry laboratory activities: Pemahaman konseptual dan keterampilan sains inkuiri pebelajar di sekolah menegah atas. *Prosiding Seminar Nasional MIPA UNIBA 2019*, 134–140. https://ejournal.unibabwi.ac.id/index.php/knmipa/article/view/795.

Febri, A., Sajidan, S., Sarwanto, S., & Harjunowibowo, D. (2020). Guided inquiry lab: Its effect to improve student's critical thinking on mechanics. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *9*(1), 87–97. https://doi.org/10.24042/jipfalbiruni.v9i1.4630

Firman, M. A., Ertikanto, C., & Abdurrahman, A. (2019). Description of meta-analysis of inquiry-based learning of science in improving students' inquiry skills. *Journal of Physics: Conference Series*, *1157*(2), 1–7. https://doi.org/10.1088/1742-6596/1157/2/022018

Ganajová, M., Sotáková, I., Lukáč, S., Ješková, Z., Jurková, V., & Orosová, R. (2021). Formative assessment as a tool to enhance the development of inquiry skills in science education. *Journal of Baltic Science Education*, *20*(2), 204–222. https://doi.org/10.33225/jbse/21.20.204.

González-Estrada, E., & Cosmes, W. (2019). Shapiro–Wilk test for skew normal distributions based on data transformations. *Journal of Statistical Computation and Simulation*, *89*(17), 3258–3272. https://doi.org/10.1080/00949655.2019.1658763

Hasanah, U., Hamidah, I., & Utari, S. (2017). Trained inquiry skills on heat and temperature concepts. *Journal of Physics: Conference Series*, *895*(1), 0–6. https://doi.org/10.1088/1742-6596/895/1/012103

Henderson, J. B., Osborne, J., Macpherson, A., & Szu, E. (2014). *A new learning progression for student argumentation in scientific contexts*. https://www.researchgate.net/publication/311666541_A_New_Learning_Progression_for_Student_Argumentation_in_Scientific_Contexts.

Hidayat, M. L. (2018). The modification of LMS quipperschool to improve senior high school students concept mastery of biology subject, Topic: Human reproduction health. *Journal of Educational Science and Technology (EST)*, *4*(1), 32–38. https://doi.org/10.26858/est.v4i1.5215

Hofstein, A., & Lunetta, V. N. (2004). The Laboratory in science education: Foundations for the twenty-first century. *Science Education*, *88*(1), 28–54. https://doi.org/10.1002/sce.10106

Hynes, M., Portsmore, M., Dare, E., Milto, E., Rogers, C., Hammer, D., & Carberry, A. (2011). Infusing engineering design into high school STEM courses. *National Center for Enggineering and Technology Education*, 8–13. https://digitalcommons.usu.edu/ncete_publications/165/.

Idris, N., Talib, O., & Razali, F. (2022). Strategies in mastering science process skills in science experiments: a systematic literature review. *Jurnal Pendidikan IPA Indonesia*, *11*(1), 155–170. https://doi.org/10.15294/jpii.v11i1.32969

Jawad, L. F., Majeed, B. H., & Alrikabi, H. T. S. (2021). The impact of teaching by using STEM approach in the development of creative thinking and mathematical achievement among the students of the fourth scientific class. *International Journal of Interactive Mobile Technologies*, *15*(13), 172–188. https://doi.org/10.3991/ijim.v15i13.24185

Kremer, K., Specht, C., Urhahne, D., & Mayer, J. (2013). The relationship in biology between the nature of science and scientific inquiry. *Journal of Biological Education*, 1–8. https://doi.org/10.1080/00219266.2013.788541

Lee, Y. A., & Takahashi, A. (2011). Lesson plans and the contingency of classroom interactions. *Human Studies*, *34*, 209–227. https://doi.org/10.1007/s10746-011-9181-1

Lubiano, M. L. D., & Magpantay, M. S. (2021). Enhanced 7E Instructional model towards enriching science inquiry skills. *International Journal of Research in Education and Science*, *7*(3), 630–658. https://doi.org/10.46328/ijres.1963

Marleni, A., & Sahono, B. (2019). Penerapan model pembelajaran inkuiri laboratorium untuk meningkatkan keterampilan proses sains dan prestasi belajar siswa. *Jurnal Imniah Teknologi Pendidikan*, *9*(1), 1–9. https://ejournal.unib.ac.id/diadik/article/download/17937/8419.

Miranti, H., Abdurrahman, & Ertikanto, C. (2018). Description of meta-analysis of science learning through inquiry model in improving students' science process skills. *International Conference on Mathematics and Science Education*, *3*, 504–508. https://doi.org/10.1088/1742-6596/1157/2/022018.

Moonsri, A., & Pattanajak, A. (2013). Lesson planning in primary school using lesson study and open approach. *Psychology*, *04*(12), 1064–1068. https://doi.org/10.4236/psych.2013.412155

Mustafa, M. N., Hermandra, & Zulhafidzh. (2021). Quality of making lesson plans by senior high school teachers in Siak Regency. *Proceeding International Conference on Islamic Education "Innovative Learning Designs to Empower Students in Digital Works," 5*, 130–135. http://conferences.uin-malang.ac.id/index.php/icied/article/view/1236.

National, R. C. (2007). *Taking science to school: Learning and teaching science in grades K-8*. The National Academies Press. https://nap.nationalacademies.org/catalog/11625/taking-science-to-school-learning-and-teaching-science-in-grades.

Newton, X. A., & Tonelli, E. P. (2020). Building undergraduate STEM majors' capacity for delivering inquiry-based mathematics and science lessons: An exploratory evaluation study. *Studies in Educational Evaluation*, *64*, 1–12. https://doi.org/10.1016/j.stueduc.2019.100833

Nilasari, E., Djatmika, E. T., & Santoso, A. (2016). Pengaruh penggunaan modul pembelajaran

kontekstual terhadap hasil belajar siswa kelas V sekolah dasar. *Jurnal Pendidikan*, *1*(7), 1399–1404. http://doi.org/10.17977/jp.v1i7.6583.
OECD. (2016). *Country note – results from PISA 2015: Indonesia*. OECD. https://www.oecd.org/pisa/PISA-2015-Indonesia.pdf.
OECD. (2018). *PISA 2015 result in focus*. https://www.oecd-ilibrary.org/education/pisa-2018-results-volume-i_5f07c754-en.
OECD. (2019). *PISA 2018 Results Combined Executive Summaries Volume I, II & III*. https://www.oecd. org/pisa/publications/pisa-2018-results.htm.
Organization for Economic Cooperation Development. (2015). *Education in Indonesia: Rising to the Challenge*. OECD Publishing. https://doi.org/10.1525/as.1951.20.15.01p0699q
Orosz, G., Németh, V., Kovács, L., Somogyi, Z., & Korom, E. (2022). Guided inquiry-based learning in secondary-school chemistry classes: a case study. *Chemistry Education Research and Practice*, *24*(1), 50–70. https://doi.org/10.1039/d2rp00110a
Osborne, J. F., Henderson, J. B., MacPherson, A., Szu, E., Wild, A., & Yao, S. Y. (2016). The development and validation of a learning progression for argumentation in science. *Journal of Research in Science Teaching*, *53*(6), 821–846. https://doi.org/10.1002/tea.21316
Ozturk, E. (2021). The effect of STEM activities on the scientific inquiry skills of pre-service primary school teachers. *Journal of Education in Science, Environment and Health Volume*, *7*(4), 295–308. https://doi.org/10.21891/jeseh.987215
Pedaste, M., Maeots, M., Leijen, A., & Sarapuu, T. (2012). Improving students ' inquiry skills through reflection and self-regulation scaffolds. *Tech., Inst., Cognition and Learning, 9*, 81–95. https://eric.ed.gov/?id=EJ1258250.
Pedaste, M., Maeots, M., Siiman, L. A., Jong, T. de, Riesen, S. A. N. van, Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: definitions and the inquiry cycle. *Educational Research Review*, *14*, 47–61. https://doi.org/10.1016/j.edu rev.2015.02.003
Perdana, R., Budiyono, Sajidan, Sukarmin, & Atmojo, I. R. W. (2019). A conceptual of teaching models inquiry-based social constructivism (IbSC). *Earth and Environmental Science*, 1–8. https://doi.org/10.1088/1755-1315/243/1/012110
Pranoto, A. M. S., Sajidan, & Prayitno, B. A. (2017). Pengembangan modul berbasis inquiry lab pada materi sistem gerak untuk meningkatkan hasil belajar siswa kelas XI SMAN 1 Mejayan. *Didaktika Biologi: Jurnal Penelitian Pendidikan Biologi*, *1*(1), 33–46. https://doi.org/10.32502/dikbio.v1i1.960.
Priemer, B., Eilerts, K., Filler, A., Pinkwart, N., Rösken-Winter, B., Tiemann, R., & Zu Belzen, A. U. (2020). A framework to foster problem-solving in STEM and computing education. *Research in Science and Technological Education*, *38*(1), 105–130. https://doi.org/10.1080/02635143.2019.1600490
Prodromou, T., & Lavicza, Z. (2018). Inquiry-based learning in statistics: When students engage with challenging problems in STEM disciplines. In *STEM Education: An Emerging Field of Inquiry* (pp. 117–131). BRILL. https://doi.org/10.1163/9789004391413_008
Purnamasari, V., & Sukanto. (2016). Pengembangan lesson plan berbasis scientific approch untuk membangun karakter kepedulian siswa di Kota Semarang. *Prosiding Seminar Nasional*, 601–612. https://doi.org/10.21831/jpk.v6i2.12047.
Purwati, R., Liestari, S. P., Suwandi, T., Wulan, A. R., & Utari, S. (2021). Profile of learning experiences and students' scientific inquiry skills in science subjects. *Proceedings of the International Conference on Educational Assessment and Policy (ICEAP 2020)*, *545*, 22–28. https://doi.org/10.2991/assehr.k.210423.059

Rohman, N. A., Rosli, R., Rambely, A. S., & Halim, L. (2022). Mathematics teachers' practices of STEM education: A systematic literature review. *European Journal of Educational Research*, *11*(3), 1245–1257. https://doi.org/10.12973/eu-jer.10.3.1541.
Safaah, E. S., Muslim, M., & Liliawati, W. (2017). Teaching science process skills by using the 5- stage learning cycle in junior high school. *IOP Conf. Series: Journal of Physics: Conf. Series*, *895*, 1–6. https://doi.org/10.1088/1742-6596/895/1/012106
Sakdiah, H., Novita, N., & Muliani. (2020). Pengembangan e-modul berbasis STEM terintegrasi pembelajaran inkuiri pada mata kuliah kajian fisika kejuruan. *Jurnal Pendidikan Fisika*, *9*(2), 99–104. https://jurnal.unimed.ac.id/2012/index.php/jpf/article/view/21206/pdf.
Saputra, H., Suhandi, A., & Setiawan, A. (2019). Profile of inquiry skills pre-service physics teacher in Aceh. *International Conference on Mathematics and Science Education*, 1–6. https://doi.org/10.1088/1742-6596/1157/3/032046
Scherer, H., McKim, A., Wang, H.-H., Dibenedetto, C., & Robinson, K. (2019). Making sense of the buzz: a systematic review of "STEM" in agriculture, food, and natural resources education literature. *Journal of Agricultural Education*, *60*(2), 28–53. https://doi.org/10.5032/jae.2019.02028

Septi, B.S, and Shofiyah, N. (2020). Psychomotor skills of pre-service teachers of natural science on melde's experiment in guided inquiry learning. *IJORER : International Journal of Recent Educational Research*, *1*(2), 108–115. https://doi.org/10.46245/ijorer.v1i2.32

Sofiani, D., Nurhayati, Sunarya, Y., & Suryatna, A. (2018). Development of guided inquiry-based laboratory worksheet on topic of heat of combustion. *International Conference on Mathematics, Science and Education 2017*, 1–6. https://doi.org/10.1088/1742-6596/983/1/012169

Song, Y., van Rijn, P., Deane, P., & Chao, S. F. (2023). Assessing argumentation skills of middle school students: a learning progression approach. *Reading and Writing*. https://doi.org/10.1007/s11145-022-10407-x

Sulawanti, E. V., Ramdani, A., Bahri, S., & Merta, I. W. (2019). Pengaruh penerapan model pembelajaran inkuiri berbasis laboratorium terhadap kemampuan psikomotorik siswa. *Jurnal Pijar Mipa*, *14*(3), 141–147. https://doi.org/10.29303/jpm.v14i3.1039

Suprapto, N. (2016). Students' attitudes towards STEM education: Voices from Indonesian junior high schools. *Journal of Turkish Science Education*, *13*(special), 75–87. https://doi.org/10.12973/tused.10172a

Suryadi, P. G. E., Agustini, K., & Sugihartini, N. (2018). Pengaruh e-modul berbasis model pembelajaran project based learning pada mata pelajaran videografi terhadap hasil belajar siswa kelas XI desain komunikasi visual di SMK Negeri 1 Sukasada. *Jurnal Nasional Pendidikan Teknik Informatika (JANAPATI)*, *7*(3), 302–314. https://doi.org/10.23887/janapati.v7i3.13433

Sutaphan, S., & Yuenyong, C. (2019). STEM education teaching approach: Inquiry from the context based. *Journal of Physics: Conference Series*, *1340*(1). https://doi.org/10.1088/1742-6596/1340/1/012003

Tabun, Y. F., Sunanrno, W., & Sukarmin. (2019). Analisis Kemampuan inkuiri siswa smp dalam penerapan levels of inquiry pada pembelajaran IPA. *Seminar Nasional Pendidikan Sains*, 128–132. https://jurnal.fkip.uns.ac.id/index.php/snps/article/view/12831.

Wells, J. G. (2016). *PIRPOSAL model of integrative STEM education: Conceptual and pedagogical framework for classroom implementation*. Technology and Engineering Teacher. https://eric.ed.gov/?id=EJ1096296.

Wen, C. T., Liu, C. C., Chang, H. Y., Chang, C. J., Chang, M. H., Fan Chiang, S. H., Yang, C. W., & Hwang, F. K. (2020). Students' guided inquiry with simulation and its relation to school science achievement and scientific literacy. *Computers and Education*, *149*(February), 103830. https://doi.org/10.1016/j.compedu.2020.103830

Wenning, C. J. (2011). The levels of inquiry model of science teaching. *J. Phys. Tchr. Educ. Online*, *6*(2), 9–16. http://www2.phy.ilstu.edu/~cjwennin/jpteo/issues/jpteo6(2)sum11a.pdf.

Wörner, S., Kuhn, J., & Scheiter, K. (2022). The best of two worlds: A systematic review on combining real and virtual experiments in science education. *Review of Educational Research*, *92*(6), 911–952. https://doi.org/10.3102/00346543221079417

Wu, H., & Hsieh, C. (2006). Developing sixth graders' inquiry skills to construct explanations in inquiry-based learning environments. *International Journal of Science Education*, *28*(11), 1289–1313. https://doi.org/10.1080/09500690600621035

Yilmaz, A., & Yanarates, E. (2022). The effect of STEM activities developed within the scope of a science course on 7th grade students' inquiry and innovative thinking skills. *International Journal of Curriculum and Instruction*, *14*(1), 274–303. https://eric.ed.gov/?id=EJ1331383.

Zhbanova, K. S. (2017). How the arts standards support STEM concepts: A journey from journal of STEM to STEAM. *Journal of STEM Arts, Crafts, and Construction*, *2*(2), 1–14. https://scholarworks. uni.edu/journal-stem-arts/vol2/iss2/1/