MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2022, 18(11), em2175
ISSN:1305-8223 (online)
OPEN ACCESS Research Paper https://doi.org/10.29333/ejmste/12499

The effect of STEM-based guided inquiry on light concept understanding and scientific explanation

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Received 23 July 2022 ▪ Accepted 25 September 2022

Abstract

This study aims to determine the effect of STEM-based guided inquiry (STEM-BGI) on light concept understanding and scientific explanation. The design of this research is a quasi-experimental pre-test-post-test control group design. The difference in effect between STEM-BGI and guided inquiry design (GID) is analyzed using the one-way MANOVA. The impact of the STEM-BGI on light concept understanding and scientific explanation is analyzed using effect size. The correlation between conceptual understanding and scientific explanation is tested by bivariate correlation analysis. The result of this study indicates that the STEM-BGI learning model is more effective in enhancing light concept understanding than the GID with an effect size coefficient of 0.81 in the high category. The STEM-BGI learning model is more effective in enhancing scientific explanation than the GID with an effect size coefficient of 0.78 in the medium category. There is a positive correlation between understanding the concept and scientific explanation. Mastery concepts and scientific explanations can help students to solve more complex problems using multidisciplinary STEM.

Keywords: effectiveness, guided inquiry, STEM approach, concept understanding, scientific explanation

INTRODUCTION

Conceptual knowledge is very important in thinking skills to solve problems, so understanding concepts is very important in learning (Englund et al., 2017). Concept understanding is the result of thinking that can be expressed in the form of principles, laws, and theories obtained from facts, events, and experiences. Conceptual understanding enables children to grasp ideas in a transferable way and can help students take what they learn in class and apply it across domains. Dimensions of concept understanding questions include restating, interpreting, exemplifying, classifying, inferring, comparing, and using. The importance of this conceptual understanding causes the learning outcomes of physics learning in the Indonesian national qualifications framework curriculum to be oriented towards understanding theoretical concepts in-depth, being able to utilize science and technology to solve problems and being able to make the right decisions based on analysis of information and data. So, those students can make the right decisions based on information and data, students need to be trained to argue critically using scientific explanations. A scientific explanation is a derived explanation of a phenomenon, using relevant evidence and reasons to support the explanation. Dimensions of scientific explanation questions consist of claim, evidence, and reasoning.

Empowerment of scientific explanations can be done by making explicit scientific explanations in the learning process (Berland & Reiser, 2008; McNeil et al., 2006). Nurdiansah et al. (2021) used scientific explanatory texts supported by analogies. This method has high effectiveness in facilitating students to reach a level of conceptual understanding. The ability of students in scientific explanations can strengthen their conceptual understanding. The ability to make and support claims in scientific explanations can help them to develop a stronger understanding of the content knowledge of the material being studied (Zohar & Nemet, 2002). In

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Contribution to the literature

- STEM-BGI learning model is more effective compared to the GID learning model in enhancing the light concept understanding and scientific explanation.
- The use of PhET media for background knowledge exploration in the STEM-BGI model will facilitate the teaching of abstract concepts and will help students become more involved in the virtual science process.
- Guided inquiry activities in STEM-BGI facilitate students to actively build simple concepts, elaborate concepts and solve complex problems. The scaffolding technique in STEM-BGI trains students to explain scientifically the concepts learned in new contexts.

addition, the ability of students to explain scientifically can train them to be critical of the claims of others, and be able to communicate their ideas well, supported by evidence and reasons.

Preliminary studies on understanding the concept of light by students of Palangkaraya State Islamic Institute and Hamzanwadi Selong University, West Nusa Tenggara, showed that 58% of the questions about the concept of light had not been understood by students. Students' misconceptions that the direction of the rays is parallel to the wavefront is a misconception due to incomplete or wrong reasoning. The students' misconceptions which think that the refraction of light is only marked by a change in the direction of the propagation of light. Students do not show a coherent understanding of abstract science concepts in various situations (Park, 2019). So, based on the analysis of the need to improve understanding of the abstract concept of light, it is found that PhET simulation is needed in a learning model (Nasir et al., 2021). A PhET simulation can represent expert models more explicitly than other materials, by showing things like explicit representations of the intensity of light, electrons, vectors, or electric fields. With this approach, PhET simulation provides a unique tool that makes learning more fun and more effective (Wieman et al., 2010). In PhET simulations, the visual display and direct interaction help answer students' questions and develop their understanding.

In addition, a preliminary study on the skills in the scientific explanation of students showed that 72% of the questions about the concept of light could be answered with scientific explanations but was not systematically arranged including claims, evidence, reasons, and supports. The student's naive claim and reasoning of the characteristics of light include students assuming the terms ray and light are the same. Based on the definition of light that can only propagate in a vacuum, students assume that light cannot propagate in a medium, whereas light can propagate on certain materials such as water and glass. Light context diagnostic results when experiencing a critical angle are still weak because 56% of respondents thought that the angle of incidence was greater than the critical angle when the refracted ray was parallel to the boundary plane of the medium. The analysis of the need to improve scientific explanation skills shows that argumentative scaffolding is needed in the flipped classroom learning strategy (Cari et al., 2022). It was found that students had positive opinions regarding the flipped classroom (Asiksoy & Ozdamli, 2016). The advantage of the flipped classroom is that students have the opportunity to learn independently and work together to solve problems in class (Mehring & Leis, 2018). Flipped classroom learning can allow students to relate new content to their schemas.

Problems in online and offline learning are shown by the inactivity of students to build conceptually independently. In online learning, students are less motivated to learn so they tend to neglect the tasks given by the teacher, the teacher has difficulty explaining the material that contains equations, and the use of the zoom application is less effective because there are still many students who are not active (Napsawati, 2020). Most of the lecturers explain the material using power points so that the opportunity for students to do virtual laboratory simulations is limited. So, many science students do not find physics interesting and many of them pass physics courses at the university level without an acceptable conceptual understanding of physics (Luangrath et al., 2011). Students usually lack a conceptual understanding (explanatory) of the science content being taught (Von Aufschnaiter & Rogge, 2010). Low initial concept understanding causes students to have difficulty connecting other concepts related to the concept being studied (Putri, 2015).

The activation of students during learning can be achieved through interactive engagement. Interactive engagement activities can improve conceptual understanding and problem-solve through active participation which is often stimulated by techniques such as cooperative group problem solving, predicting the results of class demonstrations, checking to understand followed by discussion and feedback, and contextual problem scenarios in which students must assemble principles of physics to get a solution (McDaniel et al., 2016). Activation of students in the learning process in this study was pursued through the guided inquiry design (GID) learning model.

The GID syntax has been developed by Maniotes and Kuhlthau (2014), which includes eight phases: open, immerse, explore, identify, gather, create, share, and evaluate. The open stage is opening the curiosity of students on a particular topic with essential questions about curricular content. The immerse stage is conducted to build background knowledge on a chosen topic. Explore is exploring ideas by looking for several sources. Identify stage is formulating a question in the context of an essential question. Gather is useful for gathering information that specifically addresses the focus of the theme. Create stage is to create something new meaning from the collected data. The share stage is presenting and sharing findings with others. Evaluate stage useful for reflecting on their learning.

The weakness of the GID model is that it has a syntax that is too long, so it takes a lot of time to run it. In addition, the process of collecting information is more than the reading process, not through experimental activities either real or virtual. Increasing the effectiveness of the inquiry learning process can be done by integrating with the STEM approach (Johns & Mentzer, 2016) because the STEM approach can connect scientific investigations by formulating questions that are answered through investigations before they are involved in the engineering design process to solving problems (Jackson & Mohr-Schroeder, 2018). The guided inquiry learning model that is integrated with STEM is called STEM-BGI.

STEM-BGI syntax is orientation, exploration, reasoning, creating, and communicating. The orientation phase is carried out to stimulate the interest and curiosity of students related to the problems at hand. The exploration phase is carried out by guiding students to gather information from relevant sources and conduct investigations to find the relationship between the variables involved. The reasoning phase conducted to synthesize new knowledge from research has been carried out. The creating phase is conducted to apply the concept to produce a problem-solving product. The communicating phase is a process for reporting project progress and presenting problem-solving products to others to get feedback from others.

Empowerment of students' abilities in constructing physics concepts can be achieved through modeling instruction. Modeling instruction has two phases of implementation, namely the development model and the deployment model (Jackson et al., 2008). Students collect data to create models related to physical phenomena through a practicum in the model development phase. Students use the model that has been made in solving physics problems during the model deployment phase. Physical modeling can be in the form of graphs, diagrams, and mathematical equations. Physical modeling can be used to describe, explain, and predict new phenomena (Etkina et al., 2006). In this research, the modeling instruction is taken by making physics modeling from PhET simulation data. The concept that has been built from the model development stage is continued with concept elaboration activities with new situations through structured argumentation scaffolding techniques. This phase trains students to reason and creates ways to solve more complex physics problems.

The 21st-century learning approach using STEM disciplines (science, technology, engineering, and mathematics) can be used to train students in problem-solving. The characteristic of the STEM approach is learning that is connected to the environmental context through practical activities (Vennix et al., 2018). In STEM learning, real experiences that occur every day can be brought up in learning activities to attract the attention of students to the material provided. The STEM approach applies various knowledge in finding knowledge so this approach is very suitable if it collaborates with inquiry model learning. It is known that there is an influence of the inquiry learning model on students' conceptual understanding abilities (Yanda et al., 2019). Hsu et al. (2015) use structured argumentation scaffolding in inquiry learning to improve the ability to explain. The type of inquiry chosen in this study is guided inquiry with the consideration that students are not accustomed to freeing inquiry. Students still need to be guided through provocation questions to get to the learning direction that has been designed. The guided inquiry learning model is effective for improving science process skills and students' understanding of physics concepts (Sulistiyono, 2021).

The STEM approach can link inquiry activities by formulating questions that are answered through investigations before they are involved in the engineering design process to solve problems (Jackson & Mohr-Schroeder, 2018; Kennedy & Odell, 2014). The result of developing an adaptive learning model with flipped classroom strategies, PhET media, and argumentation scaffolding techniques is the STEM-BGI learning model. The science component in this learning model is a structured argumentation scaffolding technique that is oriented to building scientific explanations. The technology components in this model are the flipped classroom strategy and PhET media. The engineering component of the STEM approach is the application of the concepts learned to produce problem-solving products through project activities. The mathematical component of the STEM approach is to use mathematical equations to analyze data and mathematical reasoning on the relationship between physical quantities. STEM-BGI learning can improve the ability of gifted students according to the 21st-century learning framework (Abdurrahman et al., 2019).

The problem of this research is the need to increase the effectiveness of the GID learning model using the STEM approach. The research question in this study can be formulated as whether there is a difference in the effect of the STEM-BGI learning model and the GID learning model on concept understanding and scientific explanation. What is the correlation between

Table 1. STEM-BGI learning model steps

Syntax	Educator activities
The day before class	
Orientation	1. Watch problem orientation videos & instructional instructions from educators sent via WhatsApp group.
	2. Read study materials sent via WhatsApp group.
Exploration	3. Doing assignments on student worksheets to build background knowledge by defining terms, interpreting the physical meaning of mathematical equations, labeling concepts, & performing PhET simulations using student worksheets.
	4. Asking about instructions/materials they do not understand through WhatsApp group
When learning	
Reasoning	5. Conduct group discussions to analyze the data that has been obtained from the PhET simulation both online & off-line.
	6. Interpret the meaning of data to build concepts.
	7. Elaborating concepts in certain contexts using structured argumentation scaffolding techniques.
Creating	8. Apply the concept to solve the problem of a case/image/video in everyday life.
	9. Conduct group discussions to design problem-solving.
	10. Completing planned problem solving,
Communicating	11. Reporting performance results on each STEM-BGI learning model syntax in groups via google meet/zoom.
	12. Each group reported only one sub-task, namely (a) definition of terms, (b) labeling of concepts & physical meanings of mathematical equations, (c) interpretation of PhET simulation data & concept elaboration, & (d) structured problem-solving.
	13. Receive comments & suggestions for improvement from educators & other students.

understanding concepts and scientific explanations? And how is the practicality of the STEM-BGI learning model to improve conceptual understanding and scientific explanation?

METHOD

This type of research is quasi-experimental. The research design used was a pretest-posttest control group design. The experimental class used the 4th semester of the physics education study program of Palangkaraya State Islamic Institute, which consisted of 14 students. The control class used students from the 6th semester of the physics education study program of Mataram State Islamic University, which consisted of 14 students. The reason the two classes were chosen was that both classes were taking the same course, namely the optical wave course. Before applying the learning model, the experimental class and the control class were first equalized by testing the initial ability to understand concepts and scientific explanations of the two classes (Ary et al., 2018). Equivalence analysis of the experimental class and control class using the F test. If $F_{calculate} \geq F_{table}$ (0.05; df_1; df_2), the class is equivalent.

Data on understanding concepts and scientific explanations were collected using a concept understanding test and a scientific explanation test. Instruments for understanding concepts and scientific explanations were developed by the researcher. The concept understanding instrument consists of 38 multiple choice questions and scientific explanation questions consisting of nine essay questions. Dimensions of concept understanding questions include restating, interpreting, exemplifying, classifying, inferring, comparing, and using. Dimensions of scientific explanation questions consist of claim, evidence, and reasoning.

The content validity of the concept understanding questions and scientific explanation questions was tested using the Aiken test, which involved eight experts. All of the Aiken coefficients of items about understanding concepts and scientific explanations are above the Aiken coefficient threshold (0.75) so that all items meet content validity. The limited-scale construct validity involved ten students and the broad-scale construct validity involved 15 students. The results of the construct validity test on concept understanding showed that 38 items out of 44 items were categorized as good. The results of the validation of the constructs of scientific explanations show that nine questions are categorized as good. The results of the reliability test for conceptual understanding and scientific explanation obtained that Cronbach's alpha is above 0.7, where the Cronbach's alpha value of conceptual understanding is 0.759 and the scientific explanation is 0.756. The reliability of the instrument for conceptual understanding and scientific explanation is reliable.

The treatment was carried out in two sessions where each session was 100 minutes face-to-face in class and the task of forming background knowledge was sent the day before learning began. The STEM-BGI learning steps are shown in **Table 1**.

The practicality of the STEM-BGI model is measured through the responses of educators and students. Data on educator and student responses to the

Table 2. Interpretation of effect size according to Cohen

Effect size (r)	Criteria
0.0≤r<0.2	Low
0.2≤r<0.8	Medium
0.8≤r≤2.0	High

Table 3. Interpretation of *N*-gain score

N-gain score	Criteria
0.0≤*N*-gain<0.3	Low
0.3≤*N*-gain<0.7	Medium
N-gain>0.7	High

implementation of the STEM-BGI learning model were collected using a Likert scale questionnaire. The practical dimensions of the learning model refer to Nieveen et al. (2006), namely implementation, efficiency, and effectiveness. Implementation means that the learning model can be implemented. Efficiency is the adequate time, effort, and cost. Effectiveness means learning syntax is oriented to achieve learning objectives. Each dimension consists of five attitude statements.

Normality test used the results of the Shapiro-Wilk and homogeneity used the Levene's test. Data is said to be normally distributed if the p-value obtained is greater than 0.05 (p>0.05). Data is said to be homogeneous if p-value obtained is greater than 0.05 (p>0.05).

The effectiveness test was tested using the one-way MANOVA analysis assisted by the SPSS program. The size of the impact of the STEM-BGI learning model to improve understanding of scientific concepts and explanations was analyzed using Cohen's formula. Cohen's d value is calculated using Eq. 1, as follows:

$$Cohen's\ d = \frac{M_1 - M_2}{\sigma_{combined}}. \quad (1)$$

For research samples that are small in number and there are several samples of the experimental class and control class, the equation is as shown in Eq. 1, with N_E indicating the amount of data for the experimental class group, N_C showing the amount of data for the control class.

$$Hedge's\ g \cong dx\left(1 - \frac{3}{4(N_E + N_C) - 9}\right). \quad (2)$$

Next, the effect size is calculated using Eq. 3, follows:

$$Size\ effect(r) = \frac{d}{\sqrt{d^2 + 4}}. \quad (3)$$

For a small sample size (<50), Cohen's d tends to over-inflate results. To avoid this, it is necessary to convert Hedge's g. Because this study uses a sample of less than 50, it is necessary to convert Cohen's d to Hedge's g. Cohen's d is corrected to be a correlation coefficient because it can increase inflation on certain variables. The effect size coefficient was interpreted using the criteria from Cohen (1988) in **Table 2**.

The increase in students' understanding of concepts and scientific explanations was tested using the normalized gain test. The formula for measuring the *N-gain* score is, as follows:

Table 4. Criteria of model practicality

Score percentage	Criteria
0≤P<21	Not good
21≤P<41	Less good
41≤P<61	Pretty good
61≤P<81	Good
81≤P<100	Very good

Note. P: Percentage of sub-variables

$$N - gain = \frac{Posttest\ score - Pretest\ score}{Ideal\ score - Pretest\ score}. \quad (4)$$

The results of the normalized gain calculation are interpreted using **Table 3** (Hake, 2002).

The data on the practicality of the STEM-BGI model were analyzed qualitatively descriptively. The criteria for justifying the practicality of the model refer to **Table 4** (Riduwan, 2016).

The relationship between the variables of concept understanding and scientific explanation was tested using bivariate correlation assisted by the SPSS program. If the value of the correlation coefficient is positive, then the relationship between the two variables is directly proportional. Otherwise, if the value of the correlation coefficient is negative, the relationship between the two variables is said to be inversely proportional.

RESULTS

Results of Descriptive Statistics

Table 5 shows a summary of the results of the post-test descriptive statistical analysis of conceptual understanding. The average concept understanding from the STEM-BGI implementation is higher than the average concept understanding from the GID learning model implementation. The standard deviation of conceptual understanding in the STEM-BGI model is smaller than the standard deviation of the GID model. The small value of this standard deviation indicates the data tends to converge toward the mean.

Table 6 shows a summary of the results of the post-test descriptive statistical analysis of scientific explanations. The mean of the scientific explanation in the STEM-BGI class is higher than that of the GID class. The standard deviation of the scientific explanation in the GID model is higher than the STEM-BGI model.

Results of Comparison of Means

Table 7 shows the results of the prerequisite analysis before the one-way MANOVA test was carried out. Concept understanding data and scientific explanations have met the pre-analysis test requirements, namely both normal and homogeneous data so that the one-way MANOVA test can be carried out.

Table 5. Descriptive statistical of post-test concept understanding

Model	Mean	n	Variance	Standard deviation	Minimum	Maximum
STEM-BGI	57.8571	14	62.440	7.90187	39.00	71.00
GID	28.9286	14	131.610	11.47214	13.00	53.00

Table 6. Descriptive statistical of post-test scientific explanation

Model	Mean	n	Variance	Standard deviation	Minimum	Maximum
STEM-BGI	74.5714	14	117.033	10.81818	52.00	96.00
GID	28.2143	14	306.951	17.52000	7.00	67.00

Table 7. Analysis prerequisite test

Testing	Kind test	Significance	Decision
Normality of concept understanding		STEM-BGI: 0.205	Normal
	Shapiro-Wilk	GID: 0.445	Normal
		STEM-BGI & GID: 0.053	Normal
Normality of scientific explanation		STEM-BGI: 0.981	Normal
		GID: 00.228	Normal
		STEM-BGI & GID: 0.063	Normal
Homogeneity	Levene	Concept understanding: 0.293	Homogeneous
		Scientific explanation: 0.299	Homogeneous

Table 8. Multivariate tests

Effect		Value	F	Hypothesis df	Error df	Sig.
Learning model	Pillai's trace	.775	43.002	2.000	25.000	.000
	Wilks' lambda	.225	43.002	2.000	25.000	.000
	Hotelling's trace	3.440	43.002	2.000	25.000	.000
	Roy's largest root	3.440	43.002	2.000	25.000	.000

Table 9. Tests of between-subjects effects

Source	Dependent variable	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	Concept understanding	5858.036	1	5858.036	60.377	.000
	Scientific explanation	15042.893	1	15042.893	70.960	.000
Learning model	Concept understanding	5858.036	1	5858.036	60.377	.000
	Scientific explanation	15042.893	1	15042.893	70.960	.000
Error	Concept understanding	2522.643	26	97.025		
	Scientific explanation	5511.786	26	211.992		
Total	Concept understanding	61103.000	28			
	Scientific explanation	94509.000	28			

Table 8 shows that the significance of the p-value of Pillai's trace, Wilks' lambda, Hotelling's trace, and Roy's largest root is less than 0.05, so the learning model has a significant effect on the dependent variable at the 95% confidence level.

The source of the learning model table in **Table 9** shows that the significance value of conceptual understanding is more than 0.05, so there is a significant difference in influence between the STEM-BGI and GID learning models on students' conceptual understanding. The significance value of scientific explanation is also less than 0.05, so there is a significant difference in the effect of the STEM-BGI and GID learning models on students' scientific explanations.

The STEM-BGI model is more effective in enhancing light concept understanding than the GID model with an effect size coefficient of 0.81 in the high category. **Table 10** shows the increase in students' understanding of light concepts by 71% in the medium category and 29% in the low category.

The STEM-BGI learning model is more effective for enhancing scientific explanations than the GID learning model with an effect size coefficient of 0.78 in the medium category.

Table 10 shows the increase in students' scientific explanations was 7% in the high category, 57% in the medium category, and 36% in the low category.

Result of Correlation Analysis

The significance value (2-tiled) between light concept understanding and scientific explanation is 0.028<0.05, which means there is a significant correlation between light concept understanding and scientific explanation. Because the Pearson correlation coefficient (r=0.586) is positive, the relationship between light concept

Table 10. *N*-gain of CU & SE

CU	Criteria	SE	Criteria
0.43	Medium	0.55	Medium
0.51	Medium	0.66	Medium
0.48	Medium	0.50	Medium
0.36	Medium	0.36	Medium
0.29	Low	0.41	Medium
0.48	Medium	0.92	High
0.26	Low	0.30	Low
0.46	Medium	0.37	Medium
0.56	Medium	0.50	Medium
0.40	Medium	0.23	low
0.63	Medium	0.40	Medium
0.25	Low	0.13	low
0.20	Low	0.50	Medium
0.38	Medium	0.71	Medium

Note. CU: Concept understanding & SE: Scientific explanation

understanding and scientific explanation is positive. Because the value of r is 0.586 so the relationship between understanding the concept and scientific explanation with a strong category.

Results of Practicality of STEM-BGI Learning Model

The response of the model lecturer to the implementation of the STEM-BGI learning model is in the very good category because the p average is 98.33. The student's response to the implementation of the STEM-BGI learning model is very good because the P average is 90.51. Educators and students respond positively to the STEM-BGI learning model so it can be said that the model is practical, that is, it can be implemented easily to achieve the learning objectives that have been set.

DISCUSSION

The STEM-BGI model is more effective than the GID model to improve light concept understanding and scientific explanation. GID is a guided information search process from various sources of information carried out by students in research projects. The GID syntax includes eight phases: open, immerse, explore, identify, gather, create, share, and evaluate. The GID model has the advantage of immersing and identifying syntax to ensure students understand the problem posed and prepare basic concepts to develop problem-solving procedures. The weakness of the GID model is that it has a syntax that is too long, so it takes a lot of time to run it. In addition, the process of collecting information is more than the reading process, not through experimental activities either real or virtual. Thus, students cannot concretize abstract concepts in the GID learning model.

To increase the effectiveness of the GID model, it is necessary to modify the long syntax into a shorter syntax. Initially, GID had eight syntaxes, then it became five syntaxes, namely orientation, exploration, reasoning, creating, and communicating. The modified syntax is integrated with the STEM approach so that the result of developing the model is called STEM-BGI.

The power of the STEM-BGI syntax to improve understanding of concepts is the exploratory part where in this syntax students build background knowledge about the theme being discussed. This exploration activity is carried out by students before entering the class with the aim of not taking up the time allocated for face-to-face learning. At this stage, students work on assignments after paying attention to the problem orientation of the teacher using a front view screen presentation video that is shared via WhatsApp group. In this exploration stage, students identify important concepts, understand concepts in the form of image representations, explain the physical meaning of mathematical equations, and perform PhET simulations to concretize abstract concepts. The mapping of important concepts on the topic being studied is very important to pay attention to so that students gain a complete understanding. Concept mapping activities effectively promote higher-order thinking and knowledge retention (Chang et al., 2016).

An improved understanding of students' light concepts can be improved with the STEM-BGI model because one of the syntaxes can facilitate students to explore abstract concepts more concretely. For example, increasing students' understanding of the concept of refraction of the value of the physical wave magnitude. Before applying the STEM-BGI learning model, students were asked whether there was light refraction when the angle of incidence was perpendicular to the plane. Most of the students answered that there was no refraction, but light would be reflected in the opposite direction to the incident ray. Students assume that so far refraction is only characterized by a change in the direction of the refracted ray but do not understand that there is also a change in the value of physical quantities such as changes in wavelength, velocity, and wave intensity.

In the exploratory syntax of STEM-BGI learning using PhET simulation, the refraction of physical waves can be modeled by measuring light intensity before and after being refracted. Measurement of the physical magnitude of the wave when there is an angle perpendicular to the plane can be seen in **Figure 1** and **Figure 2**.

Figure 1 shows the results of measuring the intensity of light before entering the field by 100%. **Figure 2** shows the results of measuring the intensity of light after entering the field of 97.97%. So, if the incident ray is perpendicular to the refractive plane, the light does not experience the direction of refraction, but there is a refraction of wave intensity of 0.3%.

PhET simulation can concretize the concept of abstract physical quantities of light intensity. In addition, through PhET simulation, it is possible to simulate the phenomena of critical angle and total

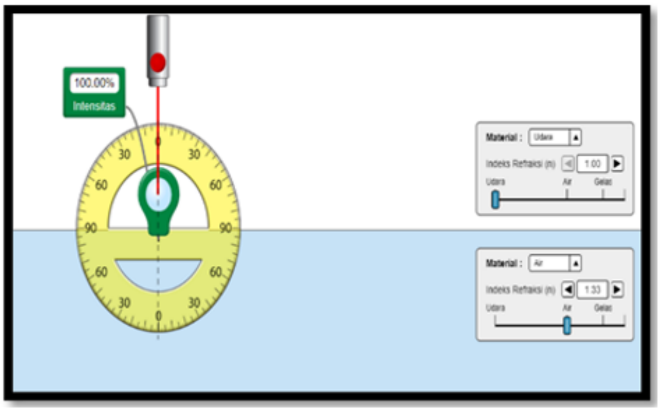


Figure 1. Measurement of the intensity of the incident light

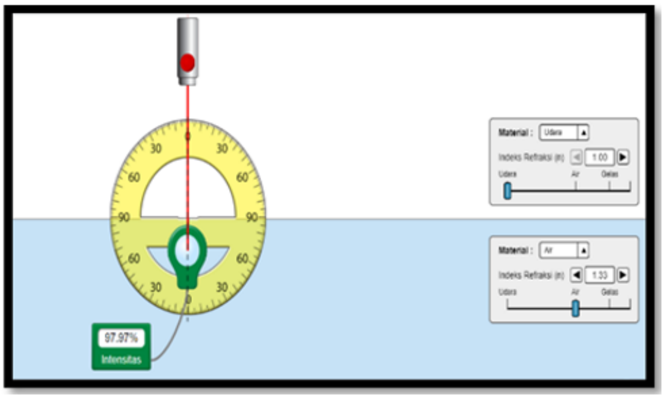


Figure 2. Measurement of the intensity of the refractive ray

Figure 3. Presentation of student simulations using PhET

internal reflection angle. Students' understanding of critical angles can be elaborated with more complex concepts in the case of refractive seismic methods.

The exploration stage of the STEM-BGI learning model makes students active in building background knowledge, either from teaching materials, PhET simulations, or other relevant references. They do not only hear direct explanations from the teacher as indirect learning.

Figure 3 shows a presentation of student simulations using PhET to concretize the refraction of wave physical quantities.

Table 11. Student simulation results about light refraction

Wave physical quantity	Observation results
Incident angle	62°
Refractive angle	41°
Intensity of the incident ray	100%
Intensity of the refractive ray	89.40%
Refractive ray direction	Moving away from the normal line
Refraction value of light intensity	0.60%

An example of student simulation results using PhET is shown in **Table 11**. Simulation of light refraction was carried out from air medium to glass medium.

The results of the study that are in line with the results of this study are the effectiveness of STEM learning with the PjBL model on creativity and understanding of science concepts for elementary school students significantly in large categories (Yulaikah et al., 2022). The STEM project-based learning approach has a major effect on students' ability to understand physics concepts (Sasmita & Hartoyo, 2020). The ability to understand mathematical concepts of students with the flipped classroom model using learning videos is better than the lecture learning method (Saputra & Mujib, 2018).

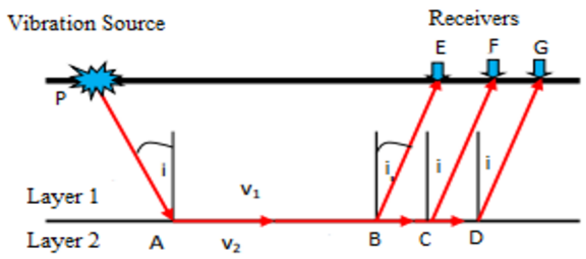
The use of virtual simulation media in an interactive conceptual learning approach can improve students' conceptual understanding and minimize misconceptions (Suhandi et al., 2009). PhET simulation-based STEM approach can improve students' understanding of physics concepts (Abdi et al., 2021). While the results of the study are not in line with these results the implementation of structured and guided inquiry did not have a significant effect on the increase of science concept understanding (Artayasa et al., 2018).

The STEM-BGI learning model can improve scientific explanations because in its syntax there is a reasoning syntax using a structured argumentation scaffolding technique with a claim, evidence, and reasoning pattern. At this stage, students use the background concept that has been built in the orientation and exploration syntax to support the claims made. The activity of elaborating concepts in creating syntax will help students to connect logical reasons between claims and evidence when giving reasons. In addition, students submit rebuttals to opponents of their claims during discussions at the communicating stage.

The reasoning syntax of STEM-BGI learning guides students to elaborate the concept of critical angle on light refraction by seismic refraction method through systematic argumentation scaffolding techniques. An example of argumentation scaffolding activity carried out in this study is shown in **Figure 4**.

An example of students' scientific explanations when elaborating concepts using structured argumentation scaffolding is, as follows:

The equipment used in refractive seismic surveys usually consists of several geophones with an interval of 2-5 meters. The source of the waves is firecrackers. The following is a sketch of the refraction seismic method of ray propagation.



Pay attention to the propagation of seismic rays in the picture above, do the seismic rays propagate parallel to the boundary planes of layer 1 and layer 2?

- Show your claim statement!
- Show evidence that supports your claim!
- Make a logical reason that shows the relationship between the claim and the evidence!

Figure 4. An example of argumentation scaffolding activity

Claim: *Yes, seismic rays propagate parallel to the boundary planes of layer 1 and layer 2.*

Evidence: *It can be seen in the figure that the wave from source P propagates in medium 1 and then refracts at a critical angle at point A so that it propagates in the layer boundary plane. This wave is refracted upward towards the receiver.*

Reason: *The angle of incidence of the seismic rays is approximately 45^o and the angle of refraction is parallel to the layer boundary so that it becomes a critical angle. This is the reason why seismic rays propagate parallel to the boundary plane.*

The structured argumentation scaffolding technique at the reasoning stage can empower students' self-explanation. Self-explanation is a process in which students make inferences about causal relationships or conceptual relationships (Bisra et al., 2018). Self-explanation helps students organize schemas into complete knowledge, facilitates complete understanding of concepts, and trains students to re-access information that has been stored in long-term memory (Tekeng, 2015). The quality of good self-explanation will affect the quality of solving physics problems (Badeau et al., 2017).

The result of the research that is in line with this research is Yang and Wang (2014) showing that students' conceptual understanding and scientific explanations in the class that uses scaffolding are better than in the control class. The results showed that students' scientific explanation skills increased significantly after they did physics learning using blended learning with e-scaffolding (Oktavianti et al., 2018). The guided inquiry learning model is considered more effective than problem-based learning for the explanatory writing activity (Palupi & Subiyantoro, 2020).

The relationship between light concept understanding and scientific explanation is positive. In other words, if the understanding of the light concept increases, the scientific explanation will also increase. Increased understanding of scientific concepts and explanations will have implications for students' problem-solving abilities.

Problem-solving ability involves complex cognitive activities to obtain information and organize it in the form of a knowledge structure. Before students obtain and organize information, it can be started by exploring student knowledge resources. Learning models for understanding concepts and applying concepts in solving physics problems should need to empower student resource searches, practice question categorization, self-explanation, and analogical comparison using worked examples (Sujarwanto, 2019).

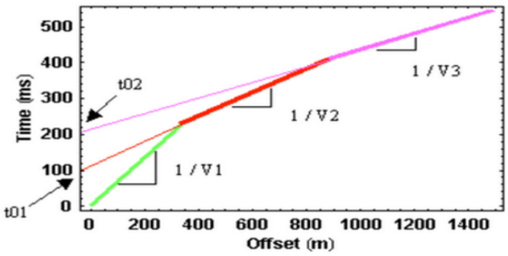
In addition, continuously enriching the content of physics courses with new applications in technology and laboratory experiments with technology will contribute to physics education (Cildir, 2016). Resource excavation activities to build background knowledge, logical reasoning for concept elaboration, and complex problem solving, as well as the use of technology in virtual laboratories are found in the STEM-BGI model syntax so that this model is effective for increasing concept understanding and scientific explanation.

Sometimes students can solve simple quantitative problems but are not able to solve more complex problems (Redish, 2005). One of the objectives of learning physics is to train students to be able to solve complex problems by applying their knowledge and understanding to everyday situations (Walsh et al., 2007). Several factors influence the difficulty of solving physics problems, namely a weak understanding of the principles and rules of physics, lack of understanding of questions, and lack of student motivation to solve problems (Ikhwanuddin et al., 2010).

The syntax of creating in STEM-BGI learning can facilitate students to solve more complex problems. At this stage, students solve problems using a cross-disciplinary STEM approach. Due to the limited time to apply STEM disciplines in solving complex problems, in the case examples the context in this study applies three STEM disciplines, namely science, mathematics, and engineering.

The scientific concept of the speed and travel time of waves is the basis for mapping geophysical information. Mathematical concepts are used to predict underground depths based on information from geophones. Engineering is used to design the poster form of the subsoil based on the information from the results of mathematical analysis. An example of solving a complex problem with a STEM context approach is shown in **Figure 5**.

Seismic refraction studies aim to map near-surface characteristics such as weathering), bedrocks, mapping groundwater, etc. The geophysical information obtained from this study is a model of the velocity and depth of the subsurface layer. The figure below shows the calculation of the velocity and layering depth of the travel time curve against offset for three horizontal layered earth models.



Based on the geophysical data in the figure above, sketch the structure of the soil layer!

Figure 5. An example of solving a complex problem with a STEM context approach

An example of student work in sketching structures that make up the soil layer is shown in **Figure 6**. Students can solve complex problems at this stage by involving three STEM disciplines, namely science, mathematics, and engineering. Students can solve problems in the form of a sketch of the subsoil structure because they can apply the concept of a critical angle, predict the depth of the layer using mathematical equations, and have creativity in designing the shape of the land structure.

Similar research results show that the correlation between conceptual understanding and scientific explanation has positive relationship (Arini et al., 2021). Our results are supported by McNeill et al. (2006) that a good understanding of the concept will build a better scientific explanation because according to Plummer (2010) in Arini et al. (2021) teaching scientific explanation starts from observation and concept formation.

The STEM-BGI learning model received a very positive response from educators and students because the range of assessment scores of students and educators is in the third quartile range and the maximum value. This STEM-BGI learning model has met the practical criteria of a learning model, namely:

1. the STEM-BGI learning model can be implemented in physics learning
2. the time, effort, and cost of using the STEM-BGI learning model are affordable, and
3. the syntax of the STEM-BGI learning model is by the purpose of this learning model, namely, to improve conceptual understanding and scientific explanation.

Students had more positive responses toward STEM-BGI than conventional learning (Parno et al., 2020).

The advantages of the STEM-BGI learning model are

1. using structured argumentation scaffolding to empower scientific explanation skills,

Figure 6. Students present a sketch of structure of the soil layer at the stage of communicating the STEM-BGI model

2. using STEM contexts to elaborate concepts in new situations,
3. facilitating students to conduct investigations, analyze data, and communicate findings, creating a fun learning atmosphere in group discussions,
4. building background knowledge through flipped classroom strategies,
5. conducting virtual experiments using PhET media to simulate abstract concepts, and
6. make students learn actively to construct concepts, reason, and solve complex problems.

The weaknesses of the STEM-BGI learning model are

1. the problem-solving task in the creation phase cannot produce a complete project product from planning to the realization of the finished product,
2. not all complex problems can be solved by involving STEM disciplines simultaneously, and
3. it requires the sincerity of students to prepare background knowledge independently through the flipped classroom strategy.

CONCLUSION

The conclusions obtained from the results of this study include that the STEM-BGI learning model is more effective in enhancing light concept understanding than the GID with an effect size coefficient of 0.81 in the high category. There is an increase in students' understanding of light concepts by 71% in the medium category and 29% in the low category. The STEM-BGI learning model is more effective in enhancing scientific explanation than the GID with an effect size coefficient of 0.78 in the medium category. The increase in students' scientific explanation is 21% in the high category, 58% in the medium category, and 21% in the low category. There is a positive correlation between understanding the concept and scientific explanation. Positive correlation shows that there is a directly proportional relationship between conceptual understanding and scientific explanation. The STEM-BGI learning model received a very positive response from educators and students.

The syntax order of the STEM-BGI learning model has implications for guiding students to construct knowledge from basic concepts to complex concepts. The basic concept is built in the orientation and exploration stages. Intermediate concepts are built by elaborating concepts through the reasoning stage to train students' scientific explanations. The basic concepts and scientific explanations that have been constructed are used to solve more complex problems at the stage of creating and communicating. To implement good STEM-BGI, students must seriously run the previous syntax. Problem-solving in project design to produce products is a challenge for the next research.

Author contributions: All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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