ORIGINAL ARTICLE

Examination of Effects of Embedding Formative Assessment in Inquiry-Based Teaching on Conceptual Learning

Simay Koksalan,[1] *Feral Ogan-Bekiroglu*[2]

1 *Middle East Technical University, Ankara, Turkey*
2 *Marmara University, Istanbul, Turkey*

Abstract: *Scaffolding in learning and teacher guidance during inquiry can be attained by formative assessment, which needs to be built into every stage of inquiry. Investigation of the effects of embedded formative assessment in inquiry-based learning on students' conceptual understanding was the aim of this study. Mixed method experimental research design including quantitative and qualitative data collection methods was used for this study. The participants were 41 students, who were in tenth grade of a suburban public high school. The study reached the following conclusions. First, formative assessment combined with inquiry-based teaching serves as a catalyst for students' conceptual learning and elevates effects of inquiry. Second, eliciting evidence of learning and feedback may be the primary stages of formative assessment in accelerating student learning and supporting student knowledge development. This study suggests that assessment should be done when teaching continuous and teachers need to adopt formative assessment while performing inquiry-based teaching.*

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About the Author*: Simay Koksalan, Department of Science and Mathematics Education, Middle East Technical University, Ankara, Turkey, E-mail: simay@metu.edu.tr*

Feral Ogan-Bekiroglu at Department of Science and Mathematics Education, Marmara University, Istanbul, Turkey, E-mail: feralbekiroglu@gmail.com. ORCID: https://orcid.org/0000-0001-6982-9675

Correspondence to*: Dr. Feral Ogan-Bekiroglu at Marmara University of Turkey.*

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Introduction

FRAMEWORK for PISA science assessment focuses on scientific competencies that include identifying scientific questions, explaining phenomena scientifically, and using scientific evidence (OECD, 2007). Scientific competencies are influenced by scientific knowledge composing of knowledge about science and knowledge of science (OECD, 2007). Knowledge about science contains scientific inquiry and scientific explanations and both inquiry and explanations are the means of science (how scientists get data) and the goals of science (how scientists use data) as the basis for explanations of phenomena (Bybee, 2008). Knowledge of science is comprised of learning of scientific concepts and this learning is seen as a form of conceptual change (Posner, Strike, Hewson, & Gertzog, 1982). According to Hewson (1992), learning a new conception means that the student understands it, accepts it, and sees that it is useful. If the new conception conflicts with an existing conception, it cannot be accepted until the student has reason to be dissatisfied with it (Hewson, 1992).

Formative assessment is the process of gathering evidence of student learning, providing feedback to students, and adjusting instructional and learning strategies that enhance achievement (McMillian, 2021). Three forms of formal formative assessment are particularly effective for helping students learn: purposeful questioning, teacher feedback, and self-assessment (Russell & Airasian, 2012). Feedback is the information given to students about how to improve their work or deepen their understanding (Russell & Airasian, 2012). Student self-assessment is a process in which students monitor and evaluate their learning and performance (McMillian, 2021). Therefore, by identifying misconceptions, providing feedback, and encouraging self-assessment, formative assessment can trigger a cognitive conflict and help students develop a deeper understanding of concepts.

Due to abstractness and unfamiliarity of science concepts, conceptual learning seems to be quite complex for most of the students (Scott, Asoko & Leach, 2007). Inquiry-based teaching (IBT), which is an instructional strategy, supports students to behave like scientists to construct knowledge (Keselman, 2003). IBT engages students in investigations to build mental frameworks and to explain their experiences (Haury, 1993) because it is assumed that science learning is about understanding and applying scientific concepts and methods instead of memorization of scientific facts (Bell, Urhahne, Schanze & Ploetzner, 2010). When students learn science in the inquiry context, they “develop epistemological understandings about nature of science and scientific knowledge, as well as relevant inquiry skills such as identifying problems, generating research questions, and designing and conducting investigations” (Abd-El-Khalick et al., 2004, p. 398), These knowledge and skills are aligned with scientific competencies in the framework that PISA determines.

Research shows that inquiry-based learning has positive contributions on cognitive knowledge of students (Alouf & Bentley, 2003; Chen & Chen, 2012; Derting & Ebert-May, 2010; Gibson & Chase, 2002; Hung, 2010; Johnson & Cuevas, 2016; Laipply, 2004; Rahmat & Chanunan, 2018; Taylor & Bilbrey, 2012). However, Minner, Levy and Century (2010) synthesized findings of 138 studies and stated that the outcomes of inquiry-based teaching have not always been positive in terms of student science conceptual learning. Since research reveals some mixed results for inquiry-based programs, instructional support would be helpful to eliminate these controversial issues. In opposite to what critics of inquiry have argued, conceptual frameworks try to increase the range of instructional supports to develop deeper understanding (Scott, Smith, Chu & Friesen, 2018). As a result, there needs to be scaffolding in learning during inquiry and this support can be attained by formative assessment. According to Chappuis et al. (2014), formative assessment includes formal and informal practices that teachers and students use to gather evidence to enhance learning. The process of formative assessment is iterative and consists of collecting, inferring and acting (Ruiz-Primo & Furtak, 2007); hence, it can support learning by developing strategies (Clark, 2012). Since teachers' role is to initialize, coach and help the inquiry process, one approach to such guiding to the students in their inquiry learning is formative assessment (Grob et al., 2021).

Inquiry cycle generally starts with the curiosity phase and then followed by the focus, explore, identification, gather, creation, sharing, and evaluation phases (NRC, 2000). In this process, assessment occurs at the end. Research shows that formative assessment affects students' science learning positively (Decristan et al., 2015; Ruiz-Primo & Furtak, 2007; Smith & Gorard, 2005; William, Lee, Harrison, Black, 2004; Yin et al., 2008). Introducing scientific inquiry and formative assessment both requires a considerable change in pedagogy (Rönnebeck et al., 2018). Formative assessment approach to teaching and learning fits well with an inquiry-based approach where the teacher's role is more about mediating the learning rather than directing the students along a specific route (Harrison et al., 2018). Students often need help in inquiry process and formative assessment helps students express their opinions and test them meticulously (Harlen, 2006). Therefore, examination of the effects of embedded formative assessment in inquiry-based learning on students' conceptual learning was the purpose of this study.

Literature Review and Research Aim

Research deals with formative assessment integrated in inquiry has been focused more on teacher practices (Bernard et al., 2019; Correia & Harrison, 2020; Grob et al., 2017; Ruiz-Primo & Furtak, 2007) and its effects on students (Bulunuz, 2017; Kusairi et al., 2021; Psycharis, 2016; Srisawasdi & Panjaburee; 2015; Yue Yin et al., 2008). Regarding these studies, researchers come to an agreement that constant assessment of students' conceptions, which is formative assessment, is essential to stimulate teaching and learning during inquiry. Even though, there is a link between students' level of performance and teachers' assessment practices, the integration of assessment and inquiry is a challenging duty and creates significant instructional challenges to teachers.

Hence, some researchers examined the impacts of formative assessment in the context of inquiry-based science education on students' outcomes. For instance, Yin et al. (2008) examined using formative assessment to promote conceptual change within a science unit taught with inquiry. They showed that the formative assessment did not have a significant influence on students' motivation, achievement, and conceptual change. Seven years later Srisawasdi and Panjaburee (2015) reached the opposite result. They examined the effects of formative assessment in simulation-based inquiry learning and conducted their study with high school students in a science course. Srisawasdi and Panjaburee found that the achievement of the experimental group in which the formative assessment was integrated with inquiry significantly differed from the control group. That is, formative assessment was a facilitator for students' conceptual learning. Additionally, Psycharis (2016) explored how scientific ability rubrics used in formative assessment process improved students' engagement during IBT and concluded that self-assessment helped them probe related questions and apply features of inquiry. Bulunuz (2017) preferred using formative assessment in inquiry-based physics courses in their studies. He discovered an increase in the level of conceptual explanation students made about the relevant concept. Finally, Kusairi et al. (2021) aimed to investigate students' struggles in understanding the physics concepts after they were taught by inquiry combined with formative assessment. Their results indicated enhancement in students' learning.

Although the value of assessing students' performance while they are engaging with inquiry activities has been understood for the last couple of years, evaluating and understanding the impact of the intervention have rarely been explored comprehensively in educational research. Besides, experimental studies mainly compared the instruction where formative assessment was implemented in inquiry-based learning with traditional or curriculum-based instruction. In order to investigate the difference formative assessment made in inquiry, both experimental and control groups should follow inquiry-based instruction. These previous works did not compare the value added by aspects of formative assessment within the context of inquiry-based learning. Based on these arguments, the research question of this study was framed as follows: Does embedding formative assessment in IBT affect students' conceptual understanding of physics? How?

Methodology

Research Design

Mixed method experimental research design including both qualitative and quantitative data collection methods was applied for this study (Cresswell & Clark, 2018). There were two groups in the research. One group named FAinIBT (Formative Assessment in IBT) participated in the physics course in which formative assessment was embedded in inquiry-based teaching while the other group named IBT (inquiry-based teaching) involved in the physics course where only inquiry-based teaching was implemented.

Participants and Settings

The participants were 41 tenth grade students studying in a suburban public high school. There were three tenth grade classes (Class A, Class B, and Class C) taught by the same physics teacher in the school. Among these three classes, Class B was selected as the FAinIBT group and Class A was selected as the IBT group by drawing lots. The number of the students in Class B was 20 while the population of the students in Class A was 21. There were also 20 students in Class C that was not selected for the study. The participants constituted of 29 female and 12 male students and their average age was 16. Anonymity was ensured by using numbers like S1 or S2 as participant identifiers.

Instructional Context

The participants were taking the physics class two hours a week when this research was conducted. The subject was geometrical optics and the instruction lasted five weeks. Students' difficulties in understanding of light, vision, and image formation have been mentioned in various researches (Chu, Treagust & Chandrasegaran, 2009; Galili & Hazan, 2000). Geometrical optics chapter included the following concepts: plane mirror, shadow, optical instruments, refraction, color, eye, lenses, and vision. The students in both groups engaged in guided inquiry to conduct research and experiments by providing them with guidance and intervention throughout the process to encourage in-depth learning (Kuhlthau, 2010). The teacher taught the same concepts and brought the same problems up in both groups. Lesson plans were prepared and experiments were conducted based on each week's learning objectives by using physical materials and simulations. Eight phases in guided inquiry design were followed in both groups to actively engage students, encourage them to ask significant questions, and provide them understanding of the content (Kuhlthau et al., 2015). The phases are as follows: Open, immerse, explore, identify, gather, create, share, and evaluate. Worksheets were constructed by taking the learning objectives of the national physics curriculum account and they were distributed to the both groups. The only difference between the groups was integration of formative assessment. Because knowledge of science was measured and compared between two groups, formative assessment was based on the students' understanding of concepts.

Each lesson in both groups started with questioning. For example, in the first week, the concepts of shadow and plane mirror were discussed and the lesson started with questions that led students to do inquiry. Videos about shadow were watched and then possible reasons underlying the situations in the videos were questioned. In this phase, the students were drawn to the open phase to arouse curiosity. The students discussed whether they came across the similar situations in their everyday lives and expressed the situation they found most interesting. When the teacher observed that everyone was curious and excited about the subject, she let them move to the next stage. During the immerse phase, they were encouraged to reveal their prior knowledge and explain the relevance of this information to the situations discussed in the classroom. In order to dip into the subject and explore, each student was asked to give a daily life example in the explore phase. In this phase, interesting ideas were presented and discussed. During the identify phase, the students worked in small groups and selected a research question. In the gather phase, the students gathered information from various sources and tested their hypothesis. During the create phase, a main result was obtained and then a common decision was reached. After that, the students shared their knowledge and compared their results with others. In the final stage, which was evaluated, the teacher evaluated the whole process.

Meantime, formative assessment cycle was embedded in the FAinIBT group. This cycle includes the following steps: eliciting evidence of learning, interpreting the evidence, identifying gap, feedback, planning learning, scaffolding new learning, and closing gap (Heritage, 2007). This cycle is also based on the common process for formative assessment whose core components are collecting data about student learning in real time, analyzing data in real time and after the lesson, and responding to student data immediately and in future lessons. Both formal and informal formative assessment practices were performed during every phase of the inquiry process in the FAinIBT group and feedback was provided to the students as both verbal and written via questioning and worksheets. For example, during the identify phase, the teacher visited the groups and checked whether the research question was proper or not. She gave feedback to the groups about their research questions by asking them how and why they chose that particular research question. During the immerse phase, the students' prior knowledge was taken into account to make instructional adjustments. In the explore phase, if there were examples that might irrelevant with the subject, the teacher provided feedback to the students for giving relevant examples. The teacher used formative assessment in the gather phase by questioning whether the students collected the right information on the subject and how deep they could proceed. For example, she asked "In which situations does the refraction occur? And what did you achieve as a result of your research?" In this way, the teacher captured the evidence of student learning and used that evidence to find the learning gap, and the students had the opportunity to understand the content and figured out the missing points. During the create phase, the teacher checked the results.

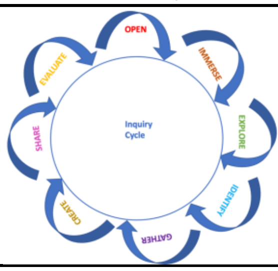
Questions were asked in both groups in order to encourage inquiry, reinforce important points, keep students' attention, and promote deeper processing of information. However, asking any type of question did not mean that the teacher was doing formative assessment. The questions that the teacher asked in the FAinIBT group served diagnostic purposes to allow the students to evaluate and compare their thinking with that of their peers to support formative assessment (Russell & Airasian, 2012). This type of questions was not used in the IBT group. **Table 1** illustrates models representing the instructional context employed in the IBT and FAinIBT groups and summary of the content week by week.

An example page for the teacher's feedback is provided in **Appendix A**. This feedback was given to the student, who was in the FAinIBT group, by writing on his worksheet distributed in the second week. The subject was refraction of light and the students filled out this worksheet during the gather stage of inquiry before doing experiments. The question was "when you make a hole on the plastic bottle filled with water and squeeze the bottle little to let the water flow, what would happen if we hold the laser towards the hole?" The student made the right prediction and wrote that "If the laser beam was sent with the right angle, it would follow the way of the water". Although his answer was correct, it was neither explanatory nor detailed. Therefore, the teacher appreciated his drawing in her feedback and asked that "What is the right angle? Why should the beam follow the way of water?" and added that "Please provide examples that we can observe the same phenomena". The self-assessment rating form that the students in the FAinIBT group used in the fifth week is shown in **Appendix B**.

Researchers' Roles

One of the researchers of this study was the physics teacher of the classes. While she was teaching, she guided and helped students throughout the in-

Table 1. Summary of the Instructional Context.

	IBT Group	FAinIBT Group
Model for the Instructional Context		
Weeks & Content	Instructional Context	Instructional Context
Week 1 Shadow and Plane Mirror	Watching videos about shadow shows. Asking questions and ensuring that prior knowledge is remembered. Achieving learning objectives by doing hands on activities with light sources, mirrors, and screens. Starting elimination of misconceptions through the activities.	Watching videos about shadow shows. Asking questions and ensuring that prior knowledge is remembered. Achieving learning objectives by doing hands on activities with light sources, mirrors, and screens. Starting elimination of misconceptions through the activities. Asking students if they could achieve the learning objectives and what they would like to learn more. Giving written feedback to their answers in the worksheets.
Week 2 Refraction	Asking daily life questions through images and making connections between phenomena (such as rainbow) and concepts. Ensuring the discovery of concepts through observations and simulation activities. Reinforcing the learning with a demonstration experiment with predict-observe-explain strategy. Sharing ideas by working with groups.	Asking daily life questions through images and making connections between phenomena (such as rainbow) and concepts. Ensuring the discovery of concepts through observations and simulation activities. Reinforcing the learning with a demonstration experiment with predict-observe-explain strategy. Sharing ideas by working with groups. Enabling students to conduct self-assessment and asking them how they could have learned better. Giving oral and written feedback.
Week 3 Lenses	Starting the lesson with discussion of wildfires in summer times. Investigation of working principles of microscopes and telescopes and presentation of the results. Exploring concepts such as focal length through simulation activities. Creating concept maps to provide the continuation of the inquiry.	Starting the lesson with discussion of wildfires in summer times. Investigation of working principles of microscopes and telescopes and presentation of the results. Exploring concepts such as focal length through simulation activities. Creating concept maps to provide the continuation of the inquiry. Enabling peer questions and providing feedback through discussions. Strengthen the outcome by requesting to think twice without giving the correct answer.
Week 4 Eye and Optical Instruments	Asking questions about eye defects and remedies. Construction of research questions and determination of image formation of lenses by watching videos and working with simulations. Discovering variety of lenses by doing hands on experiments.	Asking questions about eye defects and remedies. Construction of research questions and determination of image formation of lenses by watching videos and working with simulations. Discovering variety of lenses by doing hands on experiments. Asking further questions to the students according to their questions and answers and providing feedback.
Week 5 Color	Excitement of curiosity and enabling involvement by providing three dimensional visuals with the help of glasses. Raising questions about holograms. Doing experiments with prisms and color filters. Testing hypothesis and gathering information about the nature of color (whether it is a frequency or wavelength).	Excitement of curiosity and enabling involvement by providing three dimensional visuals with the help of glasses. Raising questions about holograms. Doing experiments with prisms and color filters. Testing hypothesis and gathering information about the nature of color (whether it is a frequency or wavelength). Asking students what they learned and how they learned and giving oral and written feedback. Students performed self-assessment.

quiry process. The following precautions were taken to prevent any bias: Instructional sequences for IBT and FAinIBT groups were prepared by two researchers together. The teacher kept anecdotes and took field notes in each lesson for both groups and discussed them with the other researcher. Moreover, inter-rater reliability was determined.

Even though having the same teacher in both groups might be a limitation due to the possible bias, this situation provided some advantages such as controlling cognitive abilities, motivation, and managing class time in both groups.

Measurement

Quantitative Data

Light and Optics Conceptual Evaluation (LOCE) test developed by Thornton and Sokoloff (1997) was applied as pre- and post-test before and after the inquiry based teaching in both groups to compare the students' conceptual understanding and find an answer for the first part of the research question. The LOCE test was chosen to use because it has high reliability and is suitable for high school students. Its adaptation study for the nation was done by (Demirci & Ahcı, 2016). A total number of questions in the test is 51 in which 50 of them are multiple choice questions whereas one of them is an open ended question. Difficulty levels of the items are between 13.9% and 76.2%. Due to the fact that, some of the questions were related to the concepts that were not covered during the inquiry-based teaching, they eliminated from the test and 37 multiple-choice questions comprised of the concepts taught were used for this study. These concepts were as follows: Image, plane mirror, focal length, refraction, vision, lenses, color, and shadow. An explanation section was added to the bottom of the all questions and the teacher requested the students to explain their reasoning behind their choices.

Qualitative Data

The students in the FAinIBT group kept reflective journals every week as a part of formative assessment. They expressed their feelings and thoughts, discussed their learning positions (which ways they chose and used), and explained the causes and consequences of situations they saw as a contribution to the process or understood their shortcomings (Hiemstra, 2001). Reflective journals helped the students do reflection and self-assessment. Therefore, these journals were also used to understand how formative assessment in inquiry-based teaching affected the students' learning. The reflective journals included the students' responses to the prompts such as what I learned, how I learned, what the purpose of the lesson was, what the most important factors were that allowed me to learn about the topic, and in what way the lesson was useful or useless for me.

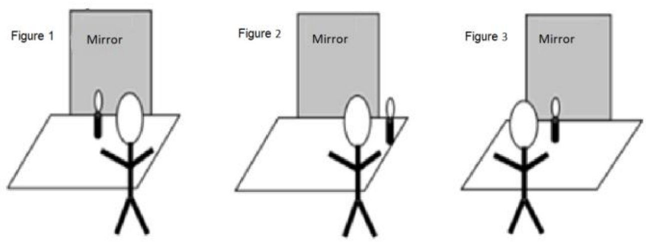
Analysis

Quantitative Data Analysis

The quantitative side of the study was conducted with 41 students studying in two groups. The students' responses to the LOCE before and after the instruction were analyzed by utilizing a scoring rubric developed based on Hogan and Fisherkeller (1996)'s coding scheme. This scheme was used in other research (Eksin & Ogan-Bekiroglu, 2013) because it enables comprehensive coding for student understanding. The coding scheme and corresponding scores are given in **Table 2**. The rubric was generated specifically for the content of each question. The overall maximum score the students could get from the LOCE was 222 while the overall minimum score was 0.
The fourth question in the LOCE and the scoring rubric for this question are shown below as an example:

Questions 1-5 refer to the three figures below of a candle on a table in front of a plane (flat) mirror.

Question 4: In Figure 3, the candle is moved back to its original location, and the person moves to the left to the new position shown. Compared to Figure 1, the location of the image of the candle is now:



A. *To the left of where it was in Figure 1;*
B. *To the right of where it was in Figure 1;*
C. *In the same location as in Figure 1;*
D. *There is no image of the candle;*
E. *Not enough information is given.*

Compatible Elaborate (6 points): C is correct. The position of the image of the object does not change according to the position of the observer in the plane mirror. If the location of the candle does not change, the location of its image will not change according to the position of the observer.

Compatible Sketchy (5 points): C is correct. Since the location of the candle remains the same, the image is also in the same place.

Table 2. Coding Scheme.

Student Response	Coding	Assigned Score
Correct choice with detailed scientific explanation.	Compatible Elaborate	6
Correct choice with superficial or inadequate scientific explanation.	Compatible Sketchy	5
Correct choice with non-scientific explanation.	Compatible/Incompatible	4
Incorrect choice with shallow explanation including inconsistent scientific knowledge.	Incompatible Sketchy	3
Incorrect choice with detailed explanation including unrelated concepts.	Incompatible Elaborate	2
A choice whether it was correct or not without any explanation.	No Evidence	1
No choice.	No Response	0

Compatible/Incompatible (4 points): C is correct. As the viewer maintains his distance from the mirror, the location of the image does not change.

Incompatible Sketchy (3 points): A is correct. The position and appearance of the candle does not change, but because the viewer changes his position, it becomes more to the left.

Incompatible Elaborate (2 points): B is correct. The image is further to the right, the viewer has moved to the left side of the mirror and the image of the candle has shifted to the right as the candle will be in line with the person.

No Evidence (1 point): Any option is marked, but the description part is left blank.

No response (0 point): The answer and explanation part is left completely blank.

The Shapiro-Wilk test was applied for normality analysis. The significance values of pre-LOCE test ($p = 0.19$) and post-LOCE test ($p = 0.50$) for the IBT group, and pre-LOCE test ($p = 0.83$) and post-LOCE test ($p = 0.53$) for the FAinIBT group were greater than 0.05. Skewness and kurtosis values also showed that the data were normally distributed; thus, paired and independent sample t-tests were performed within and between the groups. Cohen (1988)'s effect size was calculated for the t-tests to measure the magnitude of the pre-post changes for the IBT and FAinIBT groups.

Internal consistency was calculated by performing the Kuder Richardson formula 20. The value of reliability coefficient was 0.73 for the pre-test presenting that it had adequate internal consistency. On the other hand, the post-test had excellent internal consistency with reliability coefficient of 0.92. In order to assess the reliability of scoring, both researchers independently scored the students' pre- and post LOCE tests by using the coding scheme. After two researchers compared their scoring and computed the agreement for each test, they reached 92% agreement for the pre-test and the reliability measured by Cohen's κ was found as 0.76. Agreement percentage for the post-test was 95% and Cohen's κ was 0.82. Since Kappa values over 0.75 seem excellent (Fleiss, 1981), the students' scoring for their conceptual knowledge had high reliability. The researchers re-scored the responses and finalized scoring scheme.

Qualitative Data Analysis

Data obtained from the reflective journals were analyzed by using content analysis to determine the student' level of cognitive progress in conceptual learning and the role of formative assessment in this progress. These journals were read and summarized from a general point of view. Open coding was employed and codes were created by marking categories and meaningful sentences in the students' expressions in the journals. A code cloud was created and the codes were examined in terms of the relationship with each other. Categories covered the codes, but also the codes came together to create the categories. For example, one student wrote that "*I learned by doing experiment, watching videos, and researching and discussing the subject*". The underlined words attracted attention and this expression was considered appropriate to be included under the learning by applied methods (MA) code. Inter-coder agreement was calculated on random samples of approximately 30% of the journals by conducting the analyses separately. Percentages of agreement were 91% and Cohen's κ was 0.71.

Results

In accordance with the independent sample t-test results between the groups' pre-test scores, the IBT group's mean score obtained from the LOCE test ($\overline{X}_{\mathrm{preIBT}}$ = 48.23) was close to the FAinIBT group's mean score obtained from the LOCE test ($\overline{X}_{\mathrm{preFAinIBT}}$ = 45.60). As it can be seen in **Table 3**, there was no significant difference between the mean scores of the IBT and FAinIBT groups ($t_{(39)} = 0.729$, $p > 0.05$).

Paired sample t-test results indicated significant increases from pre-tests to post-tests within the groups' LOCE test scores. With regard to **Table 4,** there was a significant difference between the IBT group's mean value of pre-test and post-test ($t_{(20)} = -11.65$, $p < 0.001$). In other words, the mean score of the IBT group's post-test ($\overline{X}_{\mathrm{postIBT}}$ = 89.52) was higher than the mean score of the IBT group's pre-test ($\overline{X}_{\mathrm{preIBT}}$ = 48.23). Cohen's d value ($d = 3.03$) pointed out medium effect size.

Table 3. Independent Sample t-Test Results.

Groups	n	x̄	SD	Min. Score	Max. Score	df	t	p
IBT (Pre-Test)	21	48.23	15.79	27	85	39	0.729	0.473
FAinIBT (Pre-Test)	20	45.60	4.94	36	56			

Table 4. Paired Sample t-Test Results within the IBT Group.

Group	n	x̄	SD	df	t	p	Cohen's d
IBT (Pre-Test)	21	48.23	15.79	20	-11.65	0.000	3.03
IBT (Post-Test)	21	89.52	10.95				

Table 5. Paired Sample t-Test Results within the FAinIBT Group.

Group	n	x̄	SD	df	t	p	Cohen's d
FAinIBT (Pre-Test)	20	45.60	4.94	19	-15.42	0.000	4.17
FAinIBT (Post-Test)	20	104.15	19.19				

Table 6. Independent Sample t-Test Results Between the Groups' Post-Test Scores.

Groups	n	x̄	SD	Min. Score	Max. Score	df	t	p
IBT (Post-Test)	21	89.52	10.95	73	118	39	-2.97	0.006
FAinIBT (Post-Test)	20	104.15	19.19	72	143			

According to **Table 5**, there was also a significant difference between the mean values of pre- and post-tests of the FAinIBT ($t_{(19)}$=-15.42, p<.001). The FAinIBT group's post-test mean score ($\overline{X}_{postFAinIBT}$=104.15) was higher than the FAinIBT group's pre-test mean score ($\overline{X}_{preFAinIBT}$=45.60). Cohen's d value (d=4.17) indicated medium effect size.

Independent sample t-test results between the groups' post-test scores shown in **Table 6** presents that there was a significant difference between the mean scores of the IBT and FAinIBT groups ($t_{(39)}$ = -2.97, $p < 0.05$). The

Table 7. Mean Differences in the Groups Based on the Concepts between Pre- and Post-Tests.

Concepts	Mean Difference in IBT Group	Mean Difference in FAinIBT Group
Plane Mirror	8.14	11.15
Focal Length	8.23	9.50
Refraction	7.28	12.55
Defects of Vision	3.04	4.90
Image Properties for Lenses	3.76	3.45
Image Formation by Lenses	5.66	9.35
Shadow	3.80	6.05

Table 8. Categories, Codes, and Their Frequency Values.

Categories	Codes	Frequency
Ways of Learning	Method Applied	18
	Involving with the Process	15
Teaching Strategies	Teacher Guidance	15
	No Need to Memorize	9
	Adapting to Daily Life	12
Contributions of the inquiry	Permanent Learning	15
	Increased Inquiry Skills	12
	Learning to Learn from Feedback	18

FAinIBT group's mean score ($\overline{X}_{postFAinIBT}$ = 104.15) was quite higher than the IBT group's mean score ($\overline{X}_{postIBT}$ = 89.52).

The increase found in the participants' mean scores of the LOCE test from pre-test to post-test was analyzed based on the concepts in both groups. Findings presented in **Table 7** indicate that all the mean differences are significant ($p < 0.001$). Comparison of mean differences in two groups shows that the maximum increases occurred for the concept of refraction ($\overline{X}_{post-pre}$ = 12.55), plain mirror ($\overline{X}_{post-pre}$= 11.15), and focal length ($\overline{X}_{post-pre}$= 9.50) respectively in the FAinIBT group.

Categories and the codes with their frequency values derived from the students' reflective journals are presented in **Table 8**. Three categories and 8 codes were generated from the students' reflective journals. The categories were "ways of learning", "teaching strategies", and "contributions of the inquiry" (see **Table 8**). The code cloud displayed in **Figure 1** points out that Learning to Learn from Feedback (LLF) code and Method Applied (MA) code had the highest frequency and the most common ones. Teacher Guid-

Figure 1. Code Cloud.

ance (TG), Involving with the Process (IP), and Permanent Learning (PL) codes had the second highest frequency.

Some students' quotes about the LLF codes are as follows:

"My teacher's feedbacks reinforced my learning not only in the class but also at home and helped me to explore the joy in optics" (S6).

"My teacher's advices and feedbacks helped me realize my misconceptions and acquire the correct knowledge" (S1).

"My understanding was enhanced by my teacher's questions and feedback"(S3).

"Thanks to the questions asked by our teacher; we also understood how we should move forward in this process" (S2).

"The feedback that our teacher gave us helped me understand the parts that I was struggled with" (S5).

Examples from the students' excerpts related with the MA code are given below:

"I learned by doing experiments, watching videos, and discussing our findings from the investigations" (S6).

"Using simulations helped me understand the concepts because I made my own inferences" (S4).

Some students' statements emphasized the TG code:

"Our teacher guided us very well. When we asked a question, she asked about other examples and more questions, and allowed us to find ways to learn" (S4).

"It was great that our teacher encouraged us to answer questions and try new things" (S9).

Discussion

Assessment of inquiry has been an issue and formative assessment is a one promising practice to assess students' learning in their work (Nieminen, Häkkiöniemi & Viiri, 2021). Consequently, impacts of formative assessment integrated with inquiry on the students' knowledge of light and optics concepts were examined by collecting quantitative and qualitative data in this research. Various forms of formative assessment were used with inquiry approach in the FAinIBT group while the IBT group followed inquiry based instruction. Both groups were similar in terms of their knowledge of geometric optics concepts before the instruction.

The improvement in the students' learning in the IBT group after the instruction expresses that inquiry-based teaching created a positive effect in the students' conceptual learning of light and optics. This finding appeared also in previous research (Alouf & Bentley, 2003; Chen & Chen, 2012; Derting & Ebert-May, 2010; Hung, 2010; Johnson & Cuevas, 2016; Minner et al., 2010; Rahmat & Chanunan, 2018; Taylor & Bilbrey, 2012). Similarly, the students' in the FAinIBT group increased their knowledge, which means that embedded formative assessment in inquiry-based teaching supported the students' understanding of light and optics concepts. Comparison of two groups' results show that the students who were taught by inquiry and assessed formatively learned geometric optics concepts better than the students who were involved with inquiry based teaching but not assessed during the instruction. Other researchers also revealed parallel results (Bulunuz, 2017; Kusairi et al., 2021; Psycharis, 2016; Srisawasdi & Panjaburee, 2015). However, the findings divulged by Yin et al. (2008) contrast with the results of this study.

When students' learning was assessed concept by concept, the findings indicated that the students might expand their understanding according to the way that they demonstrated their learning achievements. Both oral and written feedbacks were given to the students while they were learning these concepts. However, eliciting evidence of learning stage of formative assessment was implemented slight differently. In the second week of the instruction, the content was refraction and the students performed self-assessment. The students learned plane mirror in the first week of the instruction and they were asked if they could achieve the learning objectives and what they would like to learn more. In the third week, the students produced and asked questions to each other while they were studying lenses and the related concepts. That is, the way of bringing out evidence of learning might affect student knowledge. Moreover, self-assessment which is a critical component of formative assessment might facilitate student learning more than the other facets of formative assessment. More specific research needs to be done on this issue.

It is very valuable to interpret the results of qualitative analyses, which supported the quantitative results; to understand how embedded formative assessment in inquiry triggered conceptual understanding. It seemed that the feedback given as oral and written was an important part of formative assessment cycle because it contributed to the students' learning most. Since telling students their score or proficiency category is not the type of feedback endorsed by the formative assessment literature (Shepard, 2008), feedback used in this study allowed the students to close the difference between what they learned and what they were supposed to learn. The way teachers use feedback contributes to the building of a learning environment that promote students' self-regulation (Correia & Harrison, 2020) because "feedback allows learners to review each set task, enabling further development of learning skills" (Higgins et al. as cited in Dorić, Lambić & Jovanović, 2021, p. 1438). The results are in agreement with the finding of Ruiz-Primo and Furtak (2007) who discovered that the teacher frequently applying components of formative assessment by eliciting questions and recognizing student's responses had students with higher performance. Teacher guidance in this study was another factor in the development of the students' learning. The study done by Aditomo and Klieme (2020) has analogous result that inquiry was positively related with learning outcomes when it incorporated teacher conceptual guidance, and negatively when it did not.

Formative assessment, especially teachers' feedback and students' self-assessment, provides instructional modifications, increases student motivation and enables students to maintain high engagement and achievement (Beesley et al., 2018; Cauley & McMillan, 2010; Fuller, 2017; Kerekovic, 2021; Leenknecht et al., 2021). This might be the case in this study because Koksalan and Ogan-Bekiroglu (2019) also discovered formative assessment in inquiry had a positive effect on the students' attitudes towards physics course. More research needs to be done to evaluate how formative assessment triggers student motivation, engagement, and learning.

Conclusion, Suggestion and Implication

Formative assessment has critical role in implementation of successful student-centered inquiry pedagogy in the classroom (Correia & Harrison, 2020). The following conclusions are drawn from the results of this study. First, formative assessment combined with inquiry-based teaching serves as a catalyst for students' conceptual learning and elevates effects of inquiry. Second, eliciting evidence of learning and feedback may be the most important steps of formative assessment in accelerating student learning and facilitating student knowledge development.

Black and Wiliam (2009) suggest classroom questioning, feedback and self-assessment as the activities to enact formative assessment. These activities were embedded in inquiry process in this study and shown as fruitful strategies in conceptual learning.

Often the term assessment for learning is used rather than formative assessment (McMillan, 2021). Assessment as learning is a particular case of assessment for learning and underscores that students should be valued participants in their own learning, able to identify their own learning gaps via constructive feedback and solve their learning needs via self-assessment (Earl & Giles, 2011). Accordingly, it can be suggested that self-assessment strategies can help the practice of assessment moves from assessment for learning to assessment as learning in inquiry-based teaching.

This study has several implications. Using formative assessment processes during instruction and implementation of formative assessment in inquiry to improve student learning are addressed in the current study. The conclusions suggest that assessment should be done when teaching continuous and teachers need to adopt formative assessment during inquiry-based teaching. Since formative assessment can provide multiple opportunities and multiple contexts for teachers to expose students' concepts (Furtak & Ruiz-Primo, 2008), "scientific inquiry learning may thus be better achieved by explaining to teachers about implementing formative assessment, so that their instruction may focus on to meet student learning goals" (Ruiz-Primo & Furtak, 2007, p. 79).

Although formative assessment has valuable contribution to learning, there are some issues such as teachers' ineffective training and their limited assessment ability problematize utilizing formative assessment (Chen, Q., Zhang, J. & Li, L. 2021). Moreover, even well-educated and experienced teachers had difficulties while integrating formative assessment in inquiry-based learning because making the assessment formative was an approach outside of the order they were used to (Bernard, et al., 2019). Consequently, in-service and pre-service teacher education programs can be designed to encourage teachers in this integration. Future studies would be conducted with an independent teacher or multiple teachers to examine the ability of the teacher to implement the formative assessment in inquiry process and investigate the interactions between teacher and students more closely. This research contributes to the assessment in science education literature by presenting how formative assessment practices applied in inquiry improve conceptual learning.

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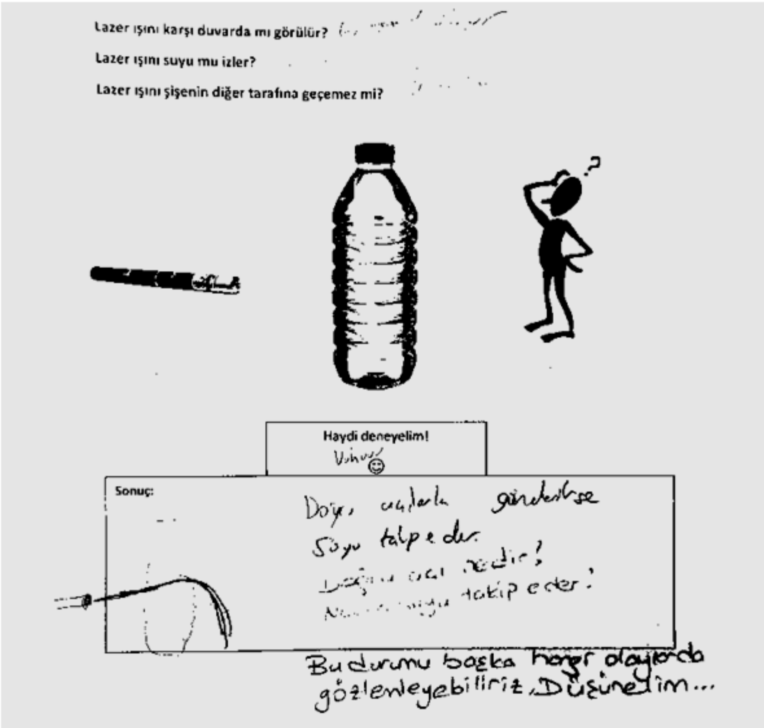
APPENDIX A

An example page for the teacher's feedback from the second week's worksheet.



APPENDIX B

Table B1. Self-Assessment Rating Form Used in the Fifth Week.

Content	Got It	Got Most of It - Just Some Fine - Tuning Needed	Got Some of It - Further Work Needed	Don't Get It at All - Help, Please
How rainbows are formed.				
How objects are seen with colors.				
How LCD TVs work.				
How holograms occur.				