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THE IMPACT OF A FORMATIVE ASSESSMENT-BASED INQUIRY MODEL ON SCIENCE STUDENT UNDERSTANDING AND EXPLANATIONS OF CHEMICAL AND PHYSICAL CHANGES

Saeed Almuntasheri
Al-Baha University, Saudi Arabia
E-mail: salmuntasheri@bu.edu.sa

Abstract

In the context of inquiry-based learning, it is widely acknowledged that fostering teachers' skills in formative assessment is vital for enhancing student learning. This study examined the impact of a formative assessment-based inquiry model on science student understanding and explanations. A quasi-experimental approach that adopts the design of two groups was used. The study sample included 62 science students enrolled in the 10th grade in Saudi Arabia who were randomly assigned to an experimental group (n = 31) or a control group (n = 31). The experimental group was taught by teachers who were engaged in professional development that embedded formative assessment into teaching 5Es inquiry learning while the control group was taught conventionally. Pre- and posttests that consisted of two sections: multiple-choice (20 questions with four alternative answers) and five open-ended questions were given to the two groups. Independent sample t-tests were performed to assess the students' understanding and explanations of physical and chemical changes. Posttest results show that students in the experimental group significantly outperformed their peers in the control group in the multiple choice and the open-ended questions. The study findings suggest the significance of integrating formative assessment with inquiry-based learning to support teachers in exploring prior knowledge and promoting learners' diverse responses. Further research should study factors that impact teachers' actions to challenge learners' thinking and encourage their inquiry to address their inconsistent views and explanations.
Keywords: *formative assessment, inquiry-based learning, student understanding, student explanations*

Introduction

Changes in matter is one of the topics in teaching basic chemistry that has been found difficult for science students. Research shows that science students face difficulties in mastering chemical and physical changes (Hanson et al., 2016; Kind, 2004). At different educational levels, science students have misconceptions in identifying the characteristics of the two changes and thus do not provide constructive evidence when explaining how a change occurs (Lott & Jensen, 2012). Chemical change includes the formation of at least one new substance and the formation of bonds between the atoms after rearranging them during chemical reactions. In physical change, the molecules are rearranged without affecting the structure of the material involved (Senese, 2016).

Some misconceptions include distinguishing between the two types of change, the conservation of mass, whether or not a change is reversible, and reasons of why a type of change occurs (Hanson et al., 2016; Kind, 2004; Lott & Jensen, 2012). For example, some students perceive that a change of matter from solid to liquid produces a new substance, and thus it is a chemical change. Learners have misconceptions in differentiating between chemical and physical changes partially due to the connection of these changes to everyday metaphorical

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forms such as cutting, melting, and burning, and they have difficulties thinking at the particle level (Yildirir & Demirkol, 2018). Superficial teaching of the difference between physical and chemical changes with the paucity of examples that enhance learner conceptual understanding leads one to the development of alternative or incorrect concepts (Hanson et al., 2016).

Researchers have reported that student-centered teaching approaches were more effective in improving students' understanding of the topic of physical and chemical changes than using traditional teaching methods (Berhanu & Sheferaw, 2022; Kingir et al., 2013). For instance, Tarhan et al. (2013) found that jigsaw cooperative learning was a more effective method to enhance conceptual understanding and prevent misconceptions in relation to changes in matter. Similarly, Kolomuc et al. (2012) revealed the effectiveness of an animation-based 5Es model on improving science students' conceptions and remediating their alternative conceptions when teaching chemical and physical changes. Berhanu and Sheferaw (2022) showed that students who were taught through guided inquiry-based learning strategy made significant improvements in their concept tests than their counterparts in a traditional group.

The term *inquiry*, however, is still used in different ways depending on the teaching practices of science teachers (Lederman et al., 2019). For example, Anderson (2007) showed that using inquiry requires ascertaining the nature of the practices involved and not assuming that we know what they mean. Other studies have confirmed that there is no unified agreement among the science education community members on the meaning of inquiry (Barrow, 2006). Thus, the concept of inquiry-based teaching and learning includes a variety of teaching methods that support students' learning but still without having a clear vision of specific guidelines on how to enact an inquiry approach in science classrooms.

Formative assessment is a method of visualizing learning progression through responsive teaching practices allowing opportunities for inquiry learning and encouraging learners' thinking and teachers' various actions (Black & William, 2009). Formative assessment practices involve gathering information about learners' current knowledge, interpreting the data gathered, and acting on the evidence to modify instruction in ways that support students' learning (Furtak et al., 2014, 2017). Effective practice of formative assessment improves outcomes for students through developing their conceptual understanding, attitudes, and motivation (Bennett, 2011; NRC, 2012; Ruiz-Primo & Furtak, 2007; Ruiz-Primo et al., 2010).

Formative assessment is a method of visualizing learning progression through responsive teaching practices, allowing opportunities for inquiry learning and encouraging learners' thinking and teachers' various actions (Black & William, 2009). In inquiry-based learning, teachers must be prepared to clearly articulate students' ideas, which means they should not only focus on identifying correct or incorrect answers but also recognize the various ideas that fall in between (Furtak, 2012). Teachers engage students by eliciting their prior knowledge, valuing their ideas, and using the collected evidence to help them provide reasons for their scientific explanations (Coffey et al., 2011; Dini et al., 2020). This approach bridges the gap between what learners already know and what they are expected to learn (Black et al., 2003; Black & William, 2009, 2018). It highlights the significance of implementing effective formative assessment practices when teaching scientific concepts (Furtak et al., 2014, 2017; Ramnarain et al., 2022).

Inquiry-Based Teaching and Learning

Inquiry-based teaching is described as "engaging students in practical experiments and activities, and about challenging and encouraging students to develop a conceptual understanding of scientific ideas" (OECD, 2016b, p. 69). The first part of this description is clearly about practical work as emphasized in the Next Generation Science Standards (NGSS, 2013), but the second part is quite vague (OECD, 2016a, 2016b). Minner et al. (2010) suggested that inquiry-based learning best supports students' conceptual understanding through scientific

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investigations that use teaching strategies to engage students in the process of learning and activate their thinking to draw conclusions from data. In the framework of the PISA 2015 assessment, the concept of inquiry-based teaching is framed in various ways, including teaching science and learning in contexts that are real and meaningful to learners (King & Ritchie, 2012; OECD, 2016a), scientific debate (Osborne, 2012), active thinking among students, and drawing conclusions from data (Minner et al, 2010).

In the field of science education, the term *inquiry* is frequently employed by specialists, but its usage can vary among science teachers based on their individual teaching approaches (Lederman et al., 2019). For example, Anderson (2007) explained that "using inquiry involves ascertaining the nature of the practices associated with it and not assuming that we know the intended meaning" (p. 808). There is a lack of consensus within the science education community regarding the precise definition of inquiry, as attested by multiple studies (e.g., Barrow, 2006). An important aspect of conducting inquiry activities is designing activities that take into account learners' engagement by encouraging their arguments and allowing opportunities for them to think scientifically (Chinn & Malhotra, 2002; McDonald, 2013)

Scientific inquiry has been classified into three main levels: open, guided, and structured. Open-ended inquiry is considered the highest level and requires high teaching experience, and training of learners in an educational environment that is equipped with the necessary tools. Open-ended inquiry, as opposed to structured inquiry, is a dynamic approach to learning (Sjøberg, 2015) where students actively engage in answering research questions using data, and acquire knowledge through experimentation, rather than relying solely on direct instruction from teachers (Bell et al., 2005)

Despite the importance of open inquiry in increasing learning opportunities and experimental practices during self-learning, there are many problems that may occur while teaching with this approach. These problems can be related to open results, which may sometimes be unexpected, and, therefore, lead to difficulty in dealing with these results; lessons may be longer because they allow further investigations to be carried out without teachers' guidance (Singer et al., 2000). Brown and Melear (2006) also noted that teachers, when initially learning about open-ended inquiry, "often experience a loss of confidence in their science content knowledge" (p. 954).

Guided inquiry falls between open-ended inquiry and structured inquiry, where the teacher guides the inquiry process by asking appropriate questions during different phases as in the 5Es learning model (Engage - Explore - Explain - Expand – Evaluate; Bybee, 2014). Studies have indicated the importance of providing support from the teacher during the five stages of learning, allowing learners to explain their understanding, apply concepts in contexts, and assess their knowledge, skills, and abilities (Bybee, 2014; Toma, 2022). Although students have fewer opportunities to plan or conduct their own experiments in this approach, they have more frequent opportunities to draw their own conclusions and interpret their ideas.

Research on Formative Assessment

Educational researchers have suggested that utilizing formative assessment as an instructional strategy can greatly benefit students by providing valuable information that guides student learning (Black et al. 2003; Srisawasdi & Panjaburee, 2015). Black and William (1998) reviewed 250 articles that investigated the effectiveness of formative assessment on student achievement. They reported considerable evidence arguing that formative assessment intervention was more influential than other strategies with effect sizes ranging from 0.40 to 0.70. Hattie (2009) examined factors that impact student learning through an evaluation of 800 studies. Formative assessment was found to be the third factor that impacts student achievement while feedback, which is considered an important element of formative assessment, was ranked as the eighth most influential factor.

Bulunuz et al. (2014) studied the effect of formative assessment on understanding physics concepts for eighth-grade students. The results showed that integration of formative assessment with extra-curricular hands-on science instruction had a significant impact on student conceptual understanding. In comparison to other groups, the pre-posttests indicated that the experimental group significantly improved their understanding of basic physics concepts. The study findings strongly suggest that direct transfer of content does not support the development of student conceptual understanding. To develop students' conceptual understanding, using formative assessment along with constructivist practices is needed in newly developed curricula. Andersson and Palm (2017) reported on the impact of a formative assessment program on student achievement in mathematics. They randomly selected 22 Year-4 mathematics teachers to participate in a professional development program that integrated formative assessment strategies. The study examined how the program changed mathematics teachers' enactment of formative assessment during classroom practice and thus its effect on student achievement. The results of the posttest indicated that the students who received intervention showed notable improvement in their performance compared to the students in the control group ($p = 0.036$, $d = 0.66$). This study reveals the importance of professional development in formative assessment and its influence on teachers' utilization of formative assessment strategies. Ultimately, this positively affects student learning outcomes.

Ozan and Kincal (2018) examined the impact of teachers' practices of formative assessment on students' achievement, attitudes, and self-regulation skills in social studies for fifth graders. The study utilized a mixed-method approach with a sample consisting of 45 students. The findings revealed a significant improvement in the academic achievement for students in the experimental group with better attitudes. Regarding students' self-learning skills, no significant differences were found between groups despite a positive impact of formative assessment on the learners in the experimental group. Lee et al. (2020) evaluated 33 studies conducted on K-12 education in the USA. The analysis indicated that formative assessment was most effective when it emphasized student-initiated formative assessment (i.e., medium-sized impact; $d = .61$). Moreover, they also found that providing formal formative assessment feedback as evidence during student learning progression was also effective ($d = .52$). The importance of these findings is in its evidence for considering learners' active role which supports the constructivist view of learning through formative assessment (Andrade & Brookhart, 2019).

Models of Formative Assessment-Based Inquiry Learning

To develop teachers' practices of formative assessment in the context of science inquiry, several researchers have discussed different professional development models. For example, Ruiz-Primo and Furtak (2006) reported on the impact of an informal formative assessment model on science teachers' assessment conversations. The ESRU conversation model was adopted in which teachers elicit (E) students' prior knowledge, listen to student (S) responses, recognize (R) students' responses, and use (U) the responses to develop further inquiry. The results showed that students performed higher when teachers used the complete ESRU cycles. However, there were differences between teachers' enactment of the ESRU model, with some teachers still facing difficulties in managing their students' requests for the correct answers. Furthermore, the teachers' focus was mostly on epistemic knowledge instead of on the conceptual features of scientific inquiry. The authors recommended the importance of formative assessment strategies during inquiry-based teaching for teacher professional development programs to improve student learning.

Oliveira (2010) conducted a study that aimed to assess science teachers' use of classroom questioning as a formative assessment strategy. Findings revealed that supporting

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science teachers to be effective questioners plays an important role in developing higher-level thinking in students and encourages them to provide longer and better articulated responses. Teachers who implemented student-centered questioning utilized initiation questions that had nonevaluative functions (referential). Follow-up questions and "reactive questions" were asked for cognitive functions such as confirmation checks that encourage students to provide affirmative responses and clarification requests that promote longer and more elaborate responses. Oliveira recommended the use of informal formative assessment strategies during science inquiry.

Similar to Ruiz-Primo and Furtak (2006), Haug and Ødegaard (2015) interviewed and videotaped conversation cycles of six elementary science teachers. They created four main categories that promote student conceptual understanding including (a) identifying learning goals, (b) eliciting students' responses, (c) interpreting the meaning of the initial ideas, and (d) taking actions or giving confirmative feedback. Findings indicated that low levels of pedagogical content knowledge impacted primary science teachers' actions after receiving students' responses. This is due to their lack of content knowledge that supported them in discussing the key concepts of a scientific idea or how to monitor the students' conceptual changes throughout the learning progression. The study suggests that teachers need support to enact formative assessment that fosters conceptual understanding in students in ways that help teachers to interpret and act on students' responses.

Furtak et al. (2017) analyzed the cycles of classroom conversations to explore the nature of informal formative assessment in middle school science classes. Results indicated that learners were more capable of sharing thoughts and ideas related to the initial eliciting questions. However, they faced difficulties in continuing the discussion after their teachers' follow-up questions. Science teachers' actions after receiving their learners' initial responses shaped the sequence of the conversation cycles and thus impacted the patterns of classroom discourse. This is important in inquiry-based teaching as teachers need to modify their instruction to support students' conceptual understanding and explanations.

Research Aim and Research Questions

The current study aimed to demonstrate the impact of a model that integrates formative assessment with inquiry-based learning on science student understandings and explanations of physical and chemical changes. The focus was on integrating formative assessment strategies into teaching with the 5Es (Engage-Explore-Explain-Expand-Evaluate) inquiry educational model. This model investigates teachers' need to make distinctions between asking evaluative and non-evaluative questions (Oliveira, 2010). Evaluative questions are teacher-centered questions that direct the classroom discussion searching for predetermined answers. Therefore, teacher-centered questions do not go beyond the elicitation of facts.

In inquiry-based learning, formative assessment strategies can be integrated to promote learning opportunities. The goal is to seek unknown information using strategies that encourage learners to predict, reason, compare, and contrast using tasks and questions that are left unsolved at the Engage phase (Bybee, 2014). The questions asked are nonevaluative which helps teachers to be aware of authoritative discourse when beginning an inquiry discussion. Rather than evaluating the initial responses after asking questions, withholding judgments of the initial ideas is required. This may help with further clarifications and encourage diverse ideas (Furtak, 2012; Ruiz-Primo & Furtak, 2006).

Two research questions guided this study:

1- What is the impact of a formative assessment-based inquiry model on science student understanding of chemical and physical changes?

2- What is the impact of a formative assessment-based inquiry model on science student explanations of chemical and physical changes?

Research Methodology

General Background

This study used a quasi-experimental design to examine the impact of a formative assessment-based inquiry model on science student understanding and explanations. This design employs experimental and control groups and compares them in pre- and posttests. The pretests were used to ensure the homogeneity of variance between the experimental and control groups and to ensure that there were no differences between them before starting the experiment. The post-tests compared the differences between the experimental and control groups after the intervention. The research took place within the second semester of the academic calendar in Saudi Arabia, which spanned from February to July of 2023.

Sample

The sample of this study included 62 science students enrolled in the 10th grade in the participating school. The 10th grade represents the first year in which students study chemistry, after studying general sciences in the intermediate stage. In this year, students study the basics of chemistry, including the topic of chemical and physical changes. This topic was taught to the study sample who were randomly assigned by school to one of the two groups: experimental or control. The experimental group (n = 31) was taught by teachers who were engaged in professional development that embedded formative assessment into teaching 5Es inquiry learning while the control group (n = 31) was taught conventionally.

Instrument and Procedures

Pre- and posttests that consisted of two multiple-choice sections (20 questions with four alternative answers) and five open-ended questions were given to the experimental and control groups. The tests covered the concepts of chemical and physical changes (Hanson et al., 2016; Kind, 2004; Lott & Jensen, 2012). Four science educators who held PhD degrees in science teaching and had more than 10 years of experience evaluated the test items. Kuder and Richardson test reveal internal consistency of 0.78 indicating the reliability of the test. The test included concepts such as distinguishing between physical and chemical changes, reversible changes, conservation of mass, and changes in which bonds are broken or formed. In the open-ended questions, students were asked to decide in different scenarios whether a physical or a chemical change occurred, and they were asked to provide scientific explanations with supporting evidence for their decisions. The scoring of the open-ended questions was adapted from Hanson et al. (2015) as shown in Table 1.

Table 1
Criteria for Scoring Levels of Conception

Degree of explanations	Criteria for scoring students' answers
Sound explanation	Multiple correct responses are given.
Partial explanation	One correct response is given.
Alternative explanation	No correct response is given.

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Data Analysis

Each variable was reviewed to ensure there were no missing data. The tests were conducted after piloting and considering the science education experts' revisions and suggestions. Reliability was examined using Cronbach's alpha which revealed an internal consistency of .78. All data in the form of multiple choice (20 items) and open-ended (five items) questions, pre- and posttests for the experimental group (n = 31) and control group (n = 31) were tested for normality through the Shapiro-Wilk test. All multiple-choice and open-ended question posttests were normally distributed (p > .05). Lavene's test result also showed that both groups were homogeneous (p > .05). Because the data were normal and homogeneous, parametric tests in the form of independent t-tests were conducted to see if there was a difference between the experimental and control groups.

Research Results

Results Related to Students' Understanding

Student understanding was assessed from the scores obtained from the multiple-choice questions (see Table 2). In the pretest, the test statistic for a two-sample independent t-test demonstrated that there was no significant difference between the experimental group (M = 5.61, SD = 1.407) and the control group (M = 5.94, SD = 1.263), with p-value > .05, p = .346. However, after the treatment, the experimental group showed better results than the control group. Posttest results showed that students in the experimental group (M = 16.97, SD = 2.483) significantly outperformed their peers in the control group (M = 13.71, SD = 2.597), p-value < .05, p = .0001 with effect size d = 1.28. Despite the significant difference in understanding chemical and physical changes in favor of the experimental group, both groups improved their scores from pre- to posttest.

Table 2
Independent Sample t-Test Results for Multiple-Choice Questions

Test	Group	N	$\bar{x}$	SD	t	p	d
Pretest	EG	31	5.6	1.4	0.95	0.34	0.25
	CG	31	5.9	1.2			
Posttest	EG	31	16.9	2.48	5.05	0.00	1.28
	CG	31	13.7	2.59			

Results Related to Students' Explanations

Student explanation skills were assessed from the scores obtained from the open-ended questions. Table 3 compares the pre- and posttests for open-ended questions. An independent sample t-test revealed no significant difference between the experimental group (M = 1.7, SD = 0.86) and the control group (M = 1.9, SD = 0.89) with p-value > .05, p = .31. In the posttest, there was a significant difference in favor of the experimental group. An independent sample t-test on posttest values showed that the experimental group had significant improvement (M = 6.77, SD = 1.23) in comparison to the control group (M = 4.7, SD = 1.33), p-value < .05, p = .0001 with effect size d = 1.56.

Table 3
Independent Sample t-Test Results for Open-Ended Questions

Test	Group	*N*	$\bar{x}$	*SD*	*t*	*p*	*d*
Pretest	EG	31	1.7	0.86	-1.01	0.31	0.26
	CG	31	1.9	0.89			
Posttest	EG	31	6.7	1.23	6.13	0.0	1.56
	CG	31	4.7	1.33			

In general, both groups experienced an increase in explaining ability as shown in posttest scores in Figures 1 and 2. While the experimental group obtained scores between Level 1 and Level 2, which indicates the learners' ability to provide sound or partial explanations, the students in the control group did not reach Level 1 which means they mostly answered with incorrect or alternative explanations. The graphs also show that the experimental and control group most often mastered Q3 which required them to distinguish between physical and chemical changes. Despite the significant improvement in overall results regarding their explanations, they had lower scores on Q1 and Q5 which required them to explain the conservation of mass during a change and the formation of new substances.

Figure 1
Pre-Post Mean Scores on Open-Ended Questions for the Experimental Group

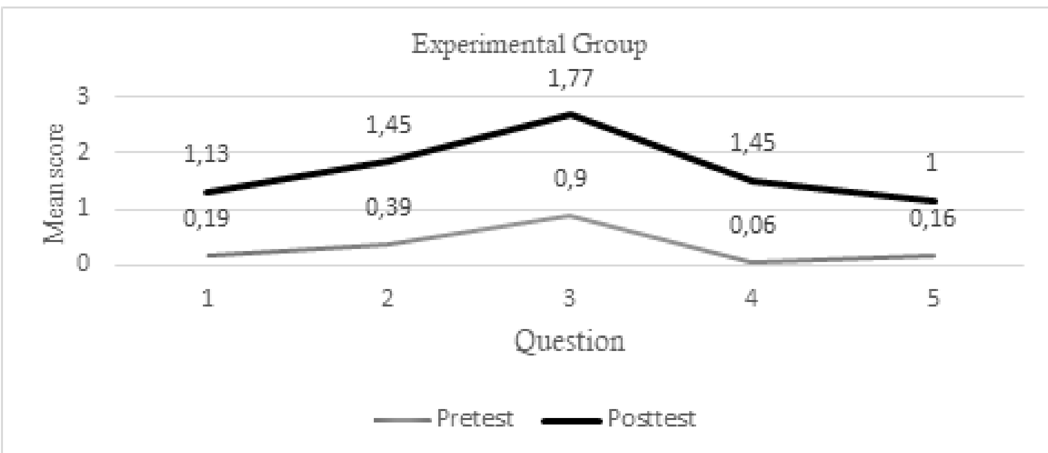
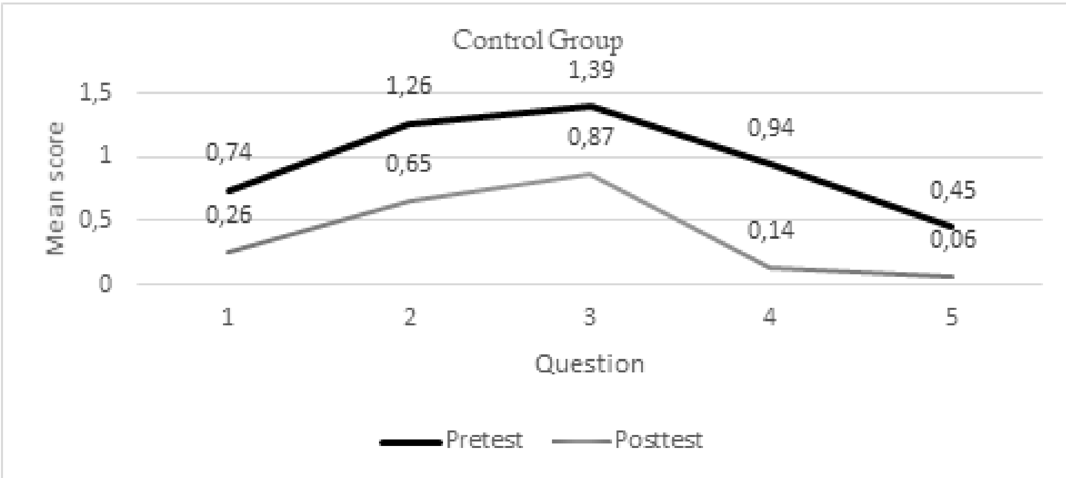


Figure 2
Pre-Post Mean Scores on Open-Ended Questions for the Control Group



Discussion

The current study revealed the positive impact of integrating formative assessment into teaching inquiry-based learning on science student understanding and explanations. The study findings show significant differences between the experimental and the control group in favor of the experimental group. Despite the improvement of both groups in the posttest compared to the pretest, in the posttest students in the experimental group scored significantly higher on various concepts in relation to chemical and physical changes. This finding is consistent with Bulunuz et al. (2014) and Ozan and Kincal (2018) who reported significance improvement in student academic achievement when designing formative assessment that helped students to apply their understanding of basic concepts using effective constructivist approaches. This is also in line with Furtak et al. (2017) who found that formative assessment strategies supported teachers in asking questions that elicited students' ideas and in using effective feedback that encouraged further inquiry. Formative assessment encourages responsive teaching which explores student ideas in the course of instruction, allowing wait time for learners to analyze the questions, but without rushing too quickly to diagnose and direct students' thinking toward the correct answers (Richards et al., 2016). The teachers' use of formative assessment helped them to ask sequential questions and to gradually follow steps to elicit their students' current understanding, make inferences from students' prior responses, and take actions that scaffolded but not directed students' thinking (Furtak, 2012; Van de Pol et al., 2018).

The experimental group's results show that learners were mostly able to distinguish between physical and chemical changes. They were also able to provide at least sound conceptions that included one reason for why a change occurred. This is in line with Bulunuz et al.'s (2014) findings suggesting the importance of using formative assessment in constructivist learning environments to develop students' conceptual understanding. However, open-ended questions indicated that some students still lacked the appropriate chemical language when explaining the causes of the changes. For example, they used the term *humidity* to explain the formation of rust on the surface of iron objects. This is similar to the results of Hanson et al. (2016) who found that 60% of their interviewees were able to distinguish between physical and chemical changes but with difficulties in using appropriate English and chemical languages.

The current findings also reveal that although the experimental group showed significant improvement in comparison to the control group, both groups had lower results in relation to questions about the loss of matter during a change. For instance, although the learners in the experimental group mostly gained skills in explaining the stability of the mass before and after a change, there were some students who explained that mass differs when paper is burned due to the volatilization of some parts in the form of ash. These responses showed that learners thought that some particles may disappear when a substance undergoes a change which suggests that some learners had misconceptions about the law of conservation of mass. This is consistent with previous studies that confirmed that learners have difficulties in understanding the conservation of mass during the occurrence of physical or chemical changes, thinking that a change in the external appearance of a substance or the rearrangement of atoms affects the mass of materials (Lott & Jensen, 2012).

Some student explanations also related chemical changes to the formation of new substances that differed from the original, but without addressing the breaking or formation of bonds or particles. Similarly, Hanson et al. (2016) noticed that some students' explanations did not include chemical reactions and their role in chemical changes, but rather focused on the change in appearance or indications of the occurrence of changes, such as a change in color or the release of fumes. This may result in students' difficulties in differentiating between chemical and physical changes. Furtak et al. (2017) found that learners faced difficulties in interacting with teachers' follow-up questions which may have impacted their conceptual understanding. Other studies found that low-level content knowledge of some science teachers may not support their actions after diagnosing their learners' prior knowledge and thus might affect the nature of discussion, leading to deficiencies in dealing with learners' various levels of conceptual understanding (Haug & Ødegaard, 2015).

Conclusions and Implications

This study's findings indicate that teaching science through integrating formative assessment and inquiry-based learning had a significant impact on 10th graders' understanding and explanations of physical and chemical changes. In contrast to the students in the control group, learners in the experimental group significantly obtained higher scores on both multiple-choice and open-ended questions. However, some learners did not achieve mastery levels in their explanations of some concepts such as their ability to comprehend that matter is conserved in chemical and physical changes. Some learners also had some difficulty in thinking about matter at the particles level.

The results of this study underscore the importance of science teachers' integration of formative assessment strategies into inquiry-based learning. These results indicate that science teachers' ability to use formative strategies during 5Es inquiry phases helps them to uncover science students' prior ideas and discuss them, then use and compare learners' responses to encourage further inquiry. This assists them to guide teaching and to modify instruction to activate the learner's role and foster scientific inquiry. Formative assessment strategies that diagnose students' thinking, value their responses, and encourage them to share their thoughts should be integrated into a framework that allows teachers to engage in discussions, create plans, and share insights on how to effectively implement these strategies to enhance inquiry-based discussions. Science teachers need to focus more on their actions and strategies after eliciting their students' prior ideas with emphasis on students' engagement, and on gradually transferring responsibility to the learners.

Further research is needed to support science teachers to learn about formative strategies that acknowledge students' contributions and promote diverse responses. Teachers need to learn about actions that challenge learners' thinking and encourage their inquiry to address students' inconsistent views and explanations. Researchers also may explore factors that hinder effective implementation of formative assessment in inquiry-based learning environments.

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Saeed Almuntasheri	PhD, Associate Professor, Al-Baha University, Saudi Arabia. E-mail: salmuntasheri@bu.edu.sa ORCID: https://orcid.org/0000-0003-4094-4295