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Research Article

The impact of formative assessment on enhancing inquiry-based learning in chemistry among secondary school students

Najeh Rajeh Ibrahim Alsalhi [1*]
0000-0002-8807-4527

Abdellateef Abdelhafez Alqawasmi [2]
0000-0002-6127-131X

Abdurrahman Ghaleb Almekhlafi [1]
0000-0002-8988-0803

[1] Department of Education, College of Arts, Humanities, and Social Sciences, University of Sharjah, Sharjah, UNITED ARAB EMIRATES
[2] College of Education, Al Ain University, Al Ain, UNITED ARAB EMIRATES
[*] Corresponding author: nalsalhi@sharjah.ac.ae

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ABSTRACT

The study aims to investigate the effect of formative assessment on improving inquiry-based learning (IBL) in chemistry topics among secondary school students. A mixed-methods quasi-experimental design was employed, integrating quantitative data from achievement tests and engagement scales with qualitative data obtained through semi-structured interviews with chemistry teachers. The participants of the study consisted of 168 students in secondary school students at Al Shola Private School in UAE in the academic year 2024-2025, divided into an experimental group (n = 85) and the other a control group (n = 83) in addition to 7 teachers who performed the practices. Experimental procedures were carried out for 5 weeks. IBL achievement tests, engagement scales, and interviews were used as data collection instruments. The results showed statistically significant differences between the experimental and the control groups in favor of the experimental group. The results also showed a significant effect of using formative assessment during IBL on the student's engagement in the experimental group. Moreover, the results also showed that achievement varied according to the gender of the students in the experimental group (in favor of females). As for the engagement, there were no statistically significant differences regarding the gender variable. Furthermore, chemistry teachers reported the positive impact of formative assessments on improving student learning through IBL.

Keywords: formative assessment, enquiry based learning, chemistry topics, constructivism, self-regulated learning

BACKGROUND AND CONTEXT OF THE STUDY

In both the current and previous centuries, there has been a tremendous transformation in all facets of life, particularly in the realms of language, science, and technology. The presence of specific individuals who dared to think unconventionally and away from the traditions that typically constrained researchers' and thinkers' actions over centuries was necessary for these changes and developments that fundamentally changed our lives. Their courage, ideas, and work helped to shape and structure the new world. Being an educator or a teacher comes with much responsibility because you raise and guide the next generation, especially in this time of rapid change. Teachers must be aware of how to prepare students for such a pace

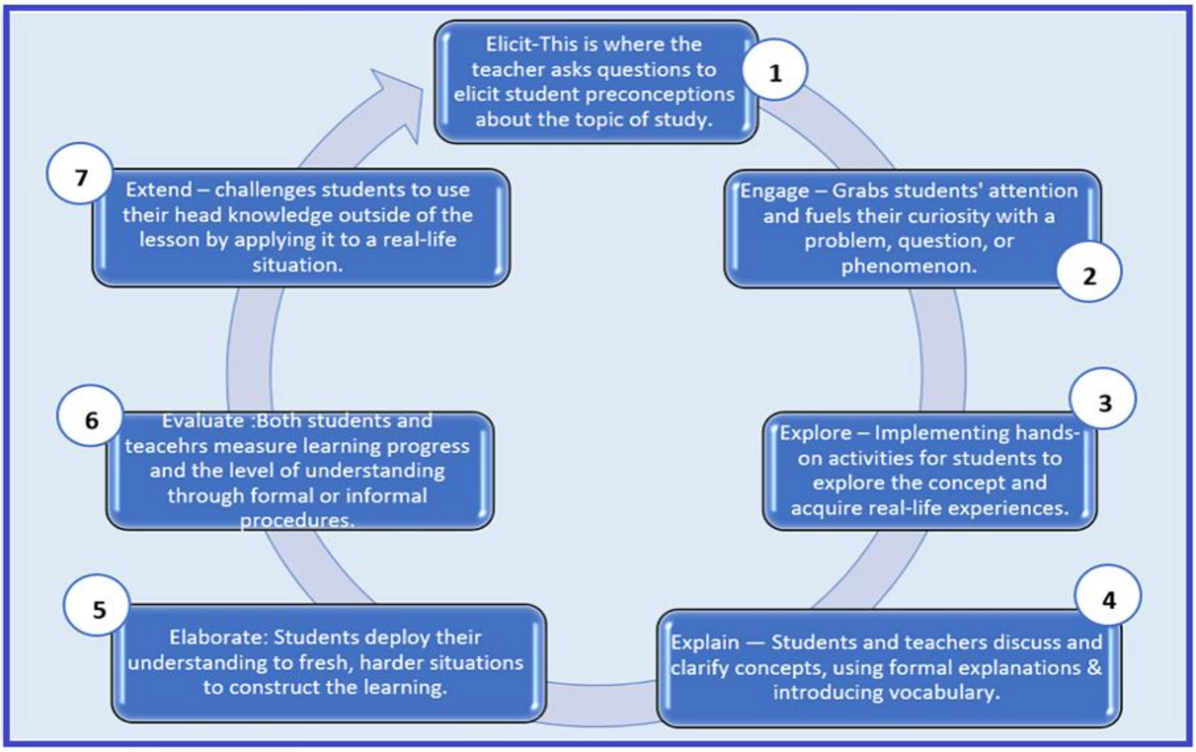

Figure 1. Inquiry cycle (7E learning cycle model) (Alsalhi, 2023)

in intelligent and adaptable ways and how to handle or endure any obstacles that may arise as they age. Moreover, numerous educational approaches have been produced and debated throughout the past century to enhance the caliber of the current teaching and learning processes. Recent research has also highlighted the challenges students face when learning chemistry at the secondary-school level. For example, Asaki and Adu-Gyamfi (2025) examined students' difficulties in learning organic chemistry and found that several conceptual and instructional factors influence students' understanding of chemistry topics. Inquiry-based learning (IBL) has been part of innovative teaching over the last decade (Grob et al., 2017). For the past ten years, creative instruction has included IBL (Grob et al., 2017). IBL shifts the educational paradigm so that students are the focus, and they do the questioning, investigating, and concluding. While teachers guide the exercise, students actively discover and develop critical thinking, creativity, and problem-solving skills. In IBL environments, students are encouraged to explore scientific problems, ask questions, and construct their understanding through investigation and discussion. However, the success of IBL also depends on the strategies used by teachers to monitor students' understanding and guide their learning during the inquiry process.

The engage, elicit, explore, explain, elaborate, evaluate, and extend (7E) learning cycle model is another technique that systematically implements IBL (Alsalhi, 2023). What it looks like: Each cycle stage drives deeper learning: Students engage with a topic, activate prior knowledge, explore concepts through hands-on activities, and explain their understanding. Then, they expand on concepts, assess their learning, and apply knowledge in new situations. Recent studies underscore the advantages of the model. Hmelo-Silver et al. (2007) revealed that the free guided exploration of the 7E model of IBL (**Figure 1**) significantly boosted critical thinking and creativity. Its effectiveness in enhancing the critical thinking of English as a foreign language students is shown by Sapriati et al. (2024). Wilson (2020) reiterated that having an inquiry framework enhances engagement, especially in science education, as it links taught lessons with real-life applications. These findings highlight how models such as the 7E learning cycle enhance IBL in achieving deep understanding and vital skills. Furthermore, IBL is an excellent strategy for inspiring, motivating, and engaging students in their studies. It gives teachers a foundation for evaluating soft skills development, which includes initiative, responsibility, and teamwork. There might be a few snags, however, the effective implementation of IBL can present several challenges, particularly when students have difficulty monitoring their understanding and evaluating their learning progress.

The 7E learning cycle is one of the instructional models used to organize IBL through stages such as engagement, exploration, explanation, elaboration, evaluation, and extension. While this model helps structure learning activities, effective inquiry-based instruction also requires continuous monitoring of students' understanding during the learning process.

In this context, formative assessment represents an important strategy for supporting learning during inquiry-based instruction. Formative assessment allows teachers to gather evidence about students' understanding, provide timely feedback, and adjust instruction accordingly. It also helps students reflect on their learning and become more actively involved in the learning process.

On the other hand, a recent call for reform made it clear that not only did reform of teaching but also that assessment methods should be changed to support a new curriculum in a way that emphasizes the creation of reasonable understanding in students rather than directing and guiding them to memorize science content (Briscoe & Wells, 2002). In IBL, assessment is an important area of instruction because "learning and assessment are mutually dependent because both students and teachers tend to pay greater attention to learning objectives that are assessed" (van Aalst, 2013, p. 280). Teachers who advocate a student-centered approach to solving poorly organized problems with no predetermined "right" answer frequently encounter difficulties. This creates a workload challenge in IBL, particularly when compared to well-structured problems with predefined answers.

Therefore, understanding how formative assessment can support students' achievement and engagement within inquiry-based chemistry classrooms has become an important issue in science education research.

Problem Statement

IBL is an excellent strategy for inspiring, motivating, and engaging students in their studies. It gives teachers a foundation for evaluating soft skills development, which includes initiative, responsibility, and teamwork. There might be a few snags, however. IBL frequently runs into issues, such as students who cannot identify their successes. Other frequent issues include dealing with pupils' weak teamwork and collaboration abilities, and their challenges in managing their work. Furthermore, the learning process will be insufficient when IBL is applied alone. The assessment strategy to be employed in learning is one of the areas that is lacking. The innovative view of science instruction emphasizes evaluation and IBL. The appropriate approaches for this learning have raised many questions and concerns for educators. Thus, this study investigated the effect of formative assessment on improving IBL in chemistry topics among secondary school students during their learning of chemistry topics.

Study Questions

1. **RQ1.** Does formative assessment affect secondary school students' achievement in chemistry subjects within IBL?
2. **RQ2.** Is there an effect of formative assessment on student engagement during IBL activities in chemistry?
3. **RQ3.** Are there statistically significant differences in achievement and engagement in chemistry topics among secondary school students based on gender when formative assessment is implemented in an IBL environment?
4. **RQ4.** What are chemistry teachers' perspectives on the experience of using formative assessments in an IBL environment?

Purpose of the Study

This study examines the effect of formative assessment on improving both academic achievement and student engagement in chemistry subjects among secondary school students in an IBL environment. Additionally, it explores whether there are any statistically significant differences in achievement and engagement based on gender when formative assessment is used.

Significance of the Study

- **Enhancing educational practices:** The study provides insights into the effectiveness of formative assessment in promoting IBL, potentially guiding educators in refining their teaching strategies.
- **Improving student outcomes:** The study examines the relationship between formative assessment, engagement, and achievement to identify methods to enhance student learning outcomes in chemistry.
- **Informing policy and curriculum development:** The research findings could inform educational policymakers and curriculum developers about the importance of integrating formative assessment practices in science education.
- **Addressing gender disparities:** Exploring gender differences in achievement and engagement can help identify and address potential educational experiences and outcomes disparities, leading to more equitable learning environments.
- **Contributing to educational research:** This study adds to the existing body of research on formative assessment and IBL, providing a foundation for future studies in various educational contexts and subjects.
- **Fostering student-centered learning:** By emphasizing the role of formative assessment in promoting student engagement, the study highlights the importance of student-centered learning approaches in fostering a more profound understanding and interest in chemistry.

THEORETICAL BACKGROUND

A school’s effectiveness in teaching and learning draws upon several external factors, including formative assessments. Formative assessments are the kind of assessment in which students get constant feedback and help identify where they need to improve. Developing thinking, inquiry, and open-ended questioning skills is an important component of an approach to science that values critical thinking and problem-solving skills. It is a learner-centered, hands-on approach to learning that allows students to determine their education. For EBL to become the predominant learning model, instructors must create an environment of discovery and questioning. We must look for educational strategies to promote student motivation and involvement. One of them is the creation of formative assessments to drive EBL. Formative testing provides feedback on learning status, helping students identify where to focus their efforts. They can take that criticism and let it guide their IBL. Moreover, in education, formative assessment is a process teachers and students use during instruction that provides feedback to adjust ongoing teaching and learning to help improve students’ achievement of intended instructional outcomes (Black & Wiliam, 1998). Where summative assessments measure learning at the end of a period, formative assessment is insertional and ongoing; it originated to mark the pathway between students and learning outcomes (Heritage, 2010). Based on numerous educational theories, this framework elucidates what formative assessment does to promote practical learning opportunities (Shute, 2008; Wiliam, 2011).

Theoretical Framework

In education, formative assessment is a process teachers and students use during instruction that provides feedback to adjust ongoing teaching and learning to help improve students’ achievement of intended instructional outcomes. Where summative assessments measure learning at the end of a period, formative assessment is insertional and ongoing; it originated to mark the pathway between students and learning outcomes. Based on numerous educational theories, this framework elucidates what formative assessment does to promote practical learning opportunities.

Theoretical Foundations

Constructivist learning theory is the idea that learners actively construct meaning by interacting with the world around them (Piaget, 1977; Vygotsky, 1978). Formative assessment easily ties into this theory and allows students to reflect, collaborate, and fully engage. Vygotsky, a Russian psychologist, introduced the zone of proximal development, which underlines how formative assessments provide teachers with the scope of understanding about what children can do with help and ensures differentiated support. They call this process "scaffolding," it is gradually letting students work by themselves as their needs are respected throughout the learning process.

Moreover, socio-cultural theory emphasizes the importance of the learner's social interaction in learning (Vygotsky, 1978). Formative assessments align more with Vygotsky's (1978) belief in the fundamental social nature of learning because formative also include collaborative learning strategies (peer assessment and group feedback sessions). By dialogic feedback, the student either engages in a dialogue with teachers or with other students—discussing statements and opinions from others, and by doing so, exchanging experiences, deepening understanding, and developing critical thinking as new perspectives are shared.

Furthermore, one of the key claims of feedback theory is that feedback is the heart of formative assessment. Hattie and Timperley (2007) argue that feedback should answer three fundamental questions: Where am I going? "How am I going?," and "Where to next?" Feedback from the formative assessment may be obtained at various levels, such as task, process, self-regulation, and self-level. They give different types of feedback to inform students how they can help advance their work, keep track of their acts of advancement, and help them justify those next steps by which learning takes place, as the process is both immediate and futuristic. Also, according to self-regulated learning theory: In this theory, your focus is on student autonomy in learning. Formative assessment empowers students to take control of their learning by setting goals, self-monitoring, and self-evaluating (Panadero, 2017). Formative assessments help learners constantly reflect on their progress and adjust their directions by promoting metacognitive skills. This constant iteration of feedback and reflection builds independence and self-regulation in learners' skills, which are critical for success throughout their academic journey.

Essential Components of Formative Assessment

Characteristics of formative assessment that enhance learning It is based upon a continuous feedback loop, in which teachers and students repeatedly provide information to each other regarding learning. The process makes it possible to adjust instruction in real-time so that teaching meets the day-to-day needs of our students. A second component is student engagement and autonomy. Formative assessment is where students are doing, not receiving. With peer- and self-assessments, learners evaluate each other's work based on set criteria to encourage deeper reflection and increased self-awareness. It encourages responsibility among the students in their learning, giving them more control in dictating how they learn. In addition, formative assessments help monitor the learning progress, essentially, the steps students take as they develop their understanding. These assessments allow educators to see where students are in their learning process so they can adjust instruction and get them to the next level. However, although formative and summative assessments serve different functions, summative data can be used formatively by analyzing it to determine what students do not know so the teacher can make instructional decisions going forward (Black & Wiliam, 1998).

Use of Technology in Formative Assessment

Formative assessments have been transformed for the better because of advanced educational technology. Digital tools like instant quizzes, auto-graded assignments, and data analytics enable teachers to offer real-time feedback and better track student progress. These technologies also make personalized learning possible by giving information on a student appraisal and helping an e-tutor so that he will interfere in time and change course if necessary. Moreover, the theoretical root of formative assessment stems from different education philosophies, such as constructivism, socio-cultural theory, feedback practice, and self-regulated learning. These theories jointly stress the importance of built-in feedback loops, engaged students, and non-linear learning strategies. Formative assessment objectivizes the learning process and makes it active and dynamic for deeper understanding, critical thinking, and metacognition for learners. The purpose is to improve student learning and emphasize the importance of accurate classroom-based assessment in shaping and modifying teachers' teaching practices and enabling improved educational outcomes.

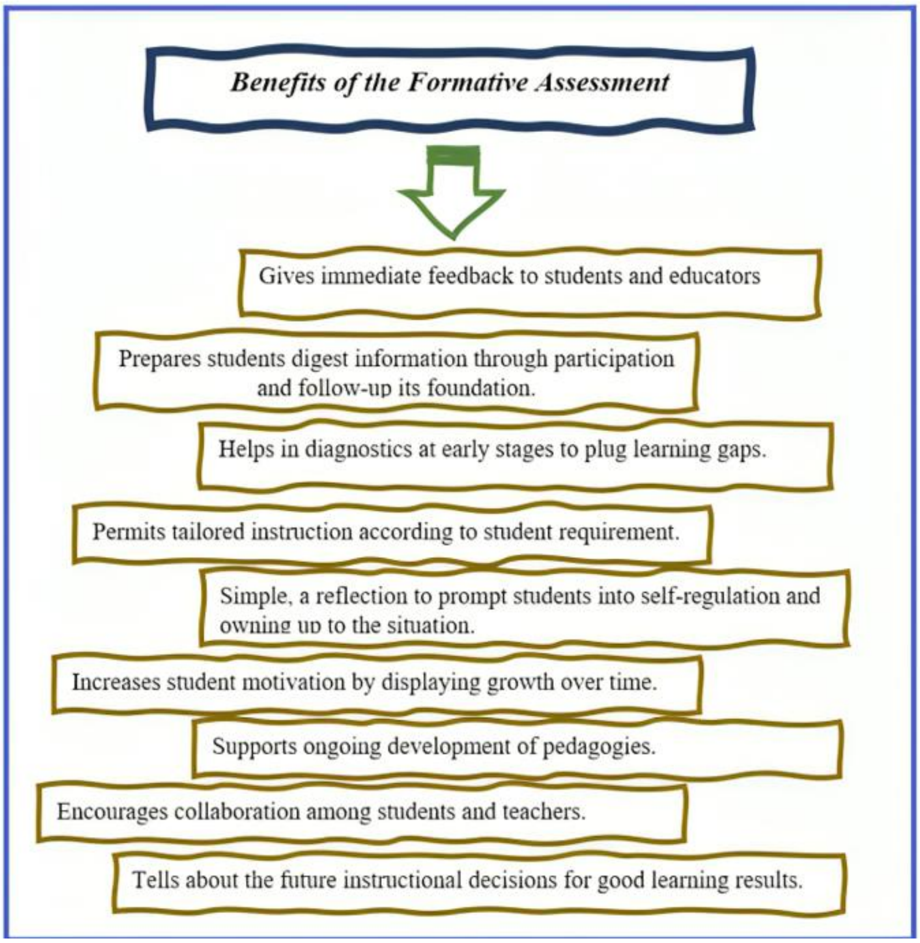

Figure 2. Benefits of the formative assessment (Source: Black & Wiliam, 1998; Hattie & Timperley, 2007)

Benefits of the Formative Assessment

According to Andrade and Cizek (2010), Black and Wiliam (1998), Brookhart (2008), Nicol and Macfarlane-Dick (2006), and Shute (2008), there are benefits for the formative assessment which can be summarized as shown in **Figure 2**.

Formative assessment is a process used to adjust teaching and learning while students are engaged in Black and Wiliam (1998). Whereas summative assessments assess learning at the end of a course, formatives allow students and teachers to monitor it throughout the process. The feedback loop, combined with the immediate availability of insights, promotes more profound understanding and affords timely intervention, rendering it essential to developing students and improving educational outcomes (Sadler, 1989; Shepard, 2000). **Figure 3** illustrates the formative assessment cycle.

PREVIOUS STUDIES

Reviewing previous studies, most confirmed the importance of formative assessment in improving students' outcomes regarding IBL. However, the studies differ in several appropriate ways. Many studies agree on integrating formative assessment into IBL. Others emphasize the role of IBL in improving students' achievement, motivation, and understanding of the material (Chan et al., 2016; Correia & Harrison, 2020; Orosz et al., 2023). To achieve this, Koksalan and Ogan-Bekiroglu (2024) and Nsabayezu et al. (2023) emphasize the importance of implementing continuous formative assessment during inquiry lessons and that the teacher has a fundamental role in preparing formative assessment to act as a facilitator of student learning (Kariri et al., 2022; Orosz et al., 2023; Tirado-Olivares et al., 2021). Formative assessment also positively enhances students' competence and academic achievement (Grob et al., 2017; Ozan & Kıncal, 2018). These studies have also confirmed that formative assessment is consistent with achieving IBL skills that lead

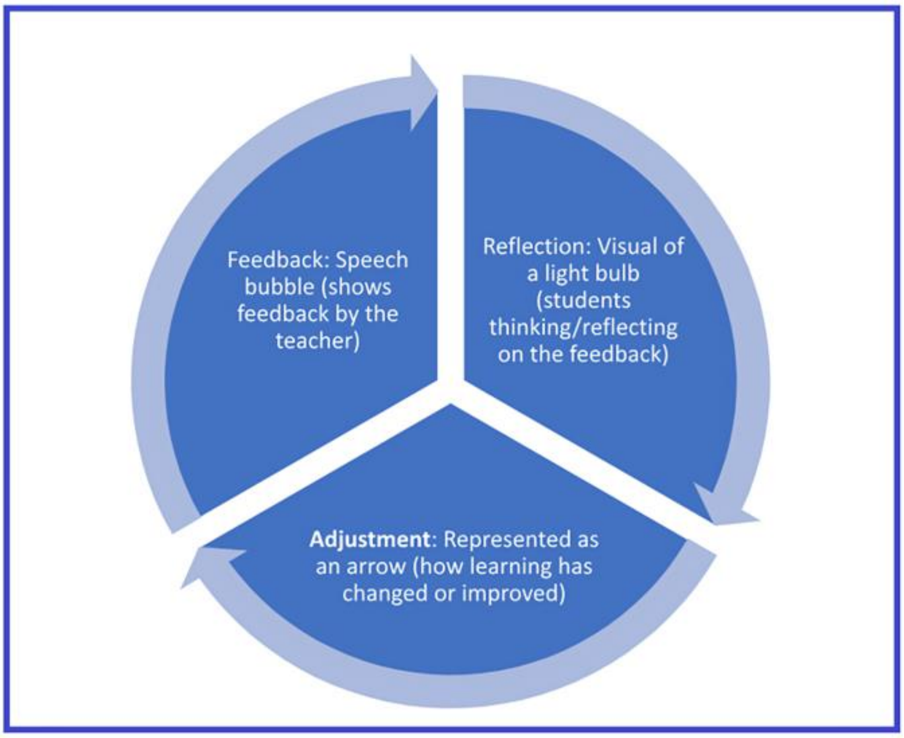

Figure 3. Formative assessment cycle (Hattie & Timperley, 2007; Shute, 2008; Wiliam, 2011)

students to a deeper understanding of knowledge elements and science skills (Alqawasmi et al., 2024; Bellido-García et al., 2024; Grob et al., 2017). Studies indicate the immediate benefits of inquiry-based formative assessment (Helle et al., 2006). In contrast, Ozan and Kıncal (2018) suggest that more time is needed to process and examine the long-term benefits. Studies also indicate the subjects in which formative assessment is implemented and the teaching stages. Some studies focused on formative assessment in science while IBL in secondary school (Grob et al., 2017), while they focused on social studies in primary school (Ozan & Kıncal, 2018). Other studies focused on cooperative learning (van Aalst, 2013), and others on individual student learning (William, 1998). Alsalhi (2023) focused on the effect of inquiry in teaching chemistry, while other studies focused on feedback in general without focusing on a specific subject. On the other hand, Tirado-Olivares et al. (2021) showed an effect of formative assessment in terms of the difference in gender in terms of the possibility of predicting male students' grades in the final assessment and the impossibility of this for female students. Regarding the structure and nature of formative assessment, Nsabayezu et al. (2023) recommend using digital assessments. Correia and Harrison (2020) do not focus on digital assessment to a large extent and approach traditional assessment methods. On the other hand, while Koksalan and Ogan-Bekiroglu (2024) see assessment as part of IBL, Hattie and Timperley (2007) recommend providing feedback on tasks, processes, and self-regulation.

Regarding feedback as an essential element of formative assessment, Nicol and Macfarlane-Dick (2006) see it as enhancing students' self-regulation by modifying their understanding and guiding them to organize their cognitive structures. It also motivates them to learn reflectively through IBL. Hattie and Timperley (2007) confirm that feedback is a powerful factor in improving academic performance when provided appropriately. Sadler (1989) states how effective feedback helps students adapt and improve their understanding in real-time. Feedback develops students' self-regulation, making them more independent and enhancing their learning responsibility (Sadler, 1989; Zimmerman, 1998). The study of Shute (2008) and Stiggins (2002) confirmed the importance of the timing of providing feedback, and when not providing it at the right time or providing it late does not help achieve the goals of formative evaluation (Sadler, 1989). Despite the important insights provided by previous studies, several issues remain insufficiently addressed in the current literature. Many studies have demonstrated the benefits of IBL and formative assessment in science education. However, these two approaches have often been examined separately rather than being studied together within the same instructional context. Another limitation in the literature is that many studies tend to examine

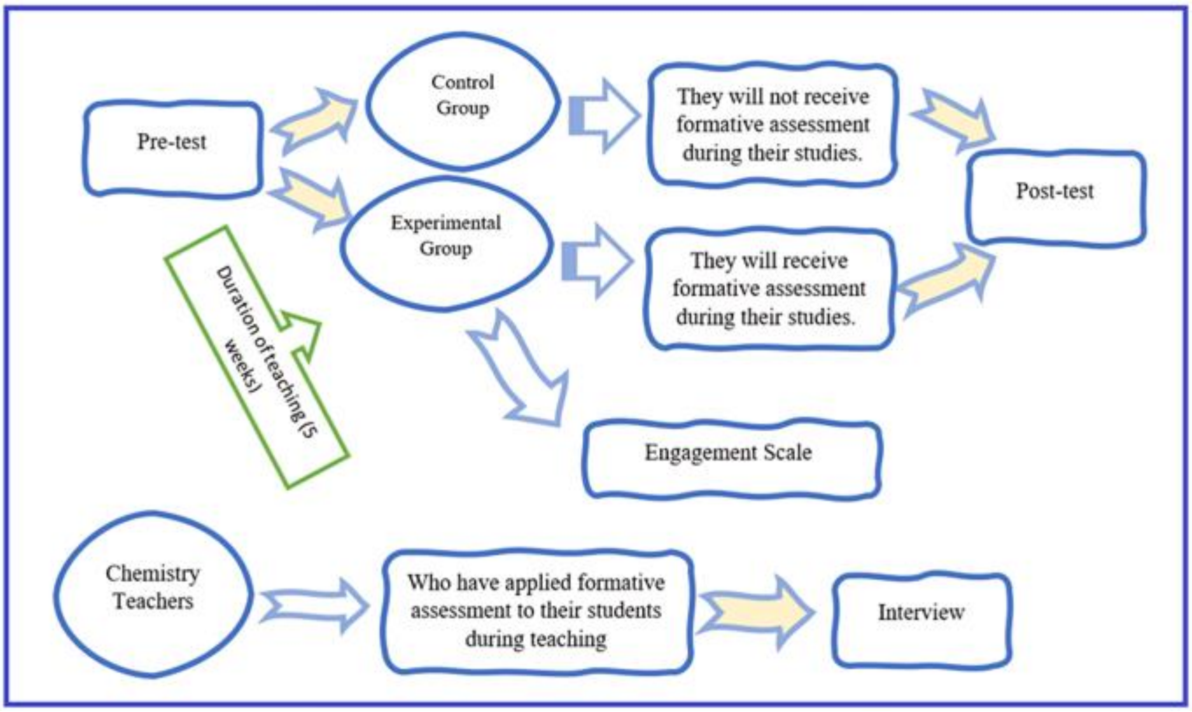

Figure 4. Design of the study (Source: Author's own elaboration)

either students' academic achievement or their engagement, while fewer studies investigate both aspects simultaneously. Moreover, the possible role of gender in shaping students' responses to formative assessment in inquiry-based chemistry learning environments has not been sufficiently explored. Finally, relatively little attention has been paid to teachers' perspectives on how formative assessment can be implemented effectively during inquiry-based instruction in chemistry classrooms. In light of these gaps, the present study investigates the impact of formative assessment on secondary-school students' achievement and engagement in chemistry within an IBL environment. The study also examines potential gender differences and explores chemistry teachers' perspectives on the use of formative assessment in this context.

METHODOLOGY

Study Design

This study adopted a mixed-methods quasi-experimental design, integrating a quantitative component and a qualitative component. The quantitative component involved a pre-/post-test control group design to examine the effect of formative assessment on students' achievement and engagement within an IBL environment. The qualitative component aimed to explore chemistry teachers' perspectives on the use of formative assessment through semi-structured interviews. The overall research design is illustrated in **Figure 4**. In line with the mixed-methods approach adopted in this study, the quantitative and qualitative instruments were designed to address the same phenomenon from complementary perspectives. While the quantitative instruments examined the impact of formative assessment on students' achievement and engagement, the qualitative interviews explored teachers' perspectives on the implementation of formative assessment within an IBL environment. This integration allowed the qualitative findings to provide contextual explanations that enriched the interpretation of the quantitative results and supported a more comprehensive understanding of the findings related to **RQ4**.

Participants

The study participants consisted of 168 secondary school students (grade 10) studying at Al Shola Private School in Ajman, United Arab Emirates, during the academic year 2024-2025. They were divided into an experimental group (n = 85) and a control group (n = 83). The study sample consisted of both experimental and control groups; however, the experimental group served as the primary focus of the intervention,

Table 1. Demographic information of participants

Group	Number		Percentage	Total
Experimental	85		51%	
Control	83		49%	
Total	168		100%	
Gender	Female (80)			
	Control	Experimental	48%	168 (100%)
	41	39		
	Male (88)			
	Control	Experimental	52%	
	42	46		

Table 2. Specification table

Topics	Understanding (35%)	Applying (25%)	Analyzing (20%)	Evaluating (15%)	Creating (5%)	Total (%)
Ion formation	10% (2 Qs)	5% (1 Qs)	5% (1 Qs)	5% (1 Qs)	0% (0 Qs)	25%
Ionic bonds and ionic compounds	10% (2 Qs)	5% (1 Qs)	5% (1 Qs)	5% (1 Qs)	0% (0 Qs)	25%
Ionic compound formulas and names	10% (2 Qs)	10% (2 Qs)	5% (1 Qs)	0% (*0* Qs)	0% (0 Qs)	25%
Metallic bonds and properties of metals	5% (1 Qs)	5% (1 Qs)	5% (1 Qs)	5% (1 Qs)	5% (1 Qs)	25%
Total	35% (7 Qs)	25% (5 Qs)	20% (4 Qs)	20% (*3* Qs)	5% (1 Qs)	100%

whereas the control group was used solely for comparison purposes. The study was conducted during the first semester of the academic year 2024-2025. **Table 1** presents the demographic characteristics of the participants.

Instruments

Achievement test

An achievement test to explore the effect of formative assessment on improving IBL in the chemistry topics of unit 3 (ionic compounds and metals) of the grade 10 textbook. It was written according to Bloom's revised taxonomy of the cognitive domain (Anderson et al., 2000; Pohl, 2000). **Table 2** shows the specifications for this test which consists of 20 multiple-choice questions and a total achievement test score of 20.

Moreover, the investigators confirmed from the content validity was evaluated by seven expert judges in science curricula, science teaching methods, science educational supervisors, and experienced science teachers, who suggested deleting some items and modifying others. The instrument was applied to a survey sample of 25 students and the Pearson correlation coefficient was calculated, and its value was equal to 0.803, which is considered appropriate to consider the test reliable.

Engagement scale: A 10-item engagement scale was prepared based on a closed Likert scale to be applied to the students of the experimental group who were taught using formative assessment during the application of IBL. To assess its reliability and validity, the engagement scale was sent to specialists from various academic institutions, who provided written feedback on the scale items that researchers could improve and modify to ensure achieving the study objective. The reliability of the engagement scale was also tested using Cronbach's alpha. The Cronbach's alpha coefficient value was 0.794, indicating a good level of internal consistency. Moreover, the Likert level will be adopted by the researchers of this study: very high (4.21-5.00), high (3.41-4.20), medium (2.61-3.40), low (1.81-2.60), and very low (1.00-1.80).

Interview

The current study aims to explore chemistry teachers' perspectives on the experience of using formative assessments in an IBL environment. An open-ended interview study was designed to collect rich and in-depth data reflecting the perspectives of four secondary school chemistry teachers on the experience of using formative assessment in an IBL environment. To ensure the validity of the interview, the question was worded to accurately reflect the topic and objectives of the study. As for reliability, the interview was introduced to 7 science teachers to ensure the stability of the results and the continuity of the responses.

Interview procedures: To conduct the interview and collect data from the four chemistry teachers, several steps were taken to ensure that accurate and comprehensive information was collected that reflects

Table 3. Means and SD of the two groups' pre-test results

Group	Frequency (f)	Mean	SD
Control	83	11.83	1.90
Experimental	85	11.75	1.57

their perspectives on the experience of using formative assessment in an inquiry-based educational environment.

- *Preparation and communication:* Prior to the interview, the four chemistry teachers were contacted and given a clear introduction about the purpose of the study and the importance of their participation in the research. A convenient time for the interview was set for them, and the general framework of the interview was explained to ensure clarity of the process and to alleviate the associated anxiety.
- *Interview implementation:* The interviews were conducted face-to-face at the school, according to the teachers' preferences and circumstances. The interview began with the main question, "What are the perspectives of chemistry teachers on the experience of using formative assessments in an inquiry-based educational environment?" Sub-questions were then directed in a flexible manner, allowing teachers to expand on their opinions and provide illustrative examples from their actual experience.
- *Data collection:* The interviews were audio-recorded to ensure that no important details were lost during the process.
- *Data analysis:* The data were analyzed using a qualitative analysis methodology that included categorizing responses and identifying recurring patterns and themes in a way that allowed for a deeper understanding of teachers' attitudes, challenges, and benefits associated with implementing formative assessment in an IBL environment.

Validity and Reliability

The validity of the research instruments was ensured through expert review. The achievement test, engagement scale, and interview questions were examined by specialists in science education and educational measurement to evaluate their clarity, relevance, and alignment with the objectives of the study. Based on their feedback, minor revisions were made to enhance the quality and appropriateness of the instruments. The reliability of the quantitative instruments was assessed using Cronbach's alpha coefficient. The analysis yielded a reliability coefficient of 0.81 for the achievement test and 0.86 for the engagement scale, indicating that both instruments demonstrated satisfactory internal consistency for measuring students' achievement and engagement. For the qualitative component, credibility was supported through the use of semi-structured interviews and consistent data collection procedures. This approach allowed teachers to express their perspectives in depth while ensuring that the data remained focused on the research questions.

Group Equivalence and Normality Testing

Prior to conducting the independent samples t-test, the normality of the pre-test scores was examined using the Shapiro-Wilk test. The results indicated that the data were normally distributed ($p > .05$), supporting the use of parametric statistical procedures. Before starting the treatment (using IBL), the equivalence of the academic achievement scores of the two groups was confirmed, as the arithmetic mean and standard deviation (SD) of the students' scores were calculated as shown in **Table 3**.

Before implementing formative assessment, the pre-test results for the topics covered in the chemistry textbook unit were compared between the two groups using an independent samples t-test. The results are displayed in **Tables 3** and **4**.

At the 0.05 level of significance, **Table 4** demonstrates that there is no statistically significant difference between the experimental and control groups. This result indicates that the obtained p-value (0.385) exceeds the 0.05 significance level, confirming the equivalence of the two groups prior to the intervention.

Table 4. t-test findings from preliminary exam comparing the control and experimental groups, respectively

	Levene's test for equality of variances		t-test			
	F	Sig.	t	df	Sig. (2-tailed)	Mean difference
Equal variances assumed	1.827	0.178	0.292	166.000	0.385	0.0784
Equal variances not assumed			0.292	158.713	0.385	0.0784

Note. *Statistically significant at p ≤ 0.05

Table 5. The mean and SDs of the academic achievement post-test scores for both groups: control and experimental groups

Group	Frequency (f)	Mean	SD
Control	83	16.02	3.38
Experimental	85	18.34	3.57

Table 6. Independent sample t-test for the two students' groups

Method	N	Mean	SD	t	df	Sig.
Control	83	16.02	3.37847	4.32	166	0.000*
Experimental	85	18.34	3.56756			

Note. *Statistically significant at p < 0.05

Data Analysis

The study utilized SPSS software to perform the descriptive analysis like frequency, mean, and SD, further to an independent sample test (t-test) and one-way ANOVA. Moreover, the interview was analyzed through a careful and comprehensive reading of the interview transcript to identify key themes and concepts. The data was categorized using a coding technique, and the data was organized according to the interview questions, focusing on common patterns and differences between the answers.

RESULTS

Results Related to RQ1

To answer this question, the means and SDs were calculated for the post-test, as shown in **Table 5**. We note from **Table 5** that the average and SD of academic achievement post-test scores for the control group were 16.02 (SD = 3.38), and for the experimental group were 18.34 (SD = 3.57). Differences between the two groups were tested using an independent samples t-test to verify whether they are significant or not; the results obtained are shown in **Table 6**.

Based on the statistical significance level of α = 0.05, **Table 6** shows that the achievement test scores of the two groups differ significantly, where the t-test statistic value = 4.32 and this means that the average academic achievement of the students of the experimental group is better than that of the students of the control group. Thus, teaching using formative assessments in an IBL environment (IBL) is better than teaching using the traditional method.

Results Related to RQ2

The mean scores and SD were calculated to address the second research question. The responses of the participants in the experimental group of students to items 1 to 10 of the questionnaire related to engagement are shown in **Table 7**.

The results shown in **Table 7** indicate that the mean for all engagement-related items (1-10) was 4.04, with a SD of 1.28. As a result, the students in the experimental group, through formative assessment, are more engaged in learning chemistry topics during IBL activities. Therefore, it is clear from **Table 7** that students' responses to Item A10 ("Formative assessment makes me think analytically and systematically about implementing inquiry-based learning activities.") had the highest mean consensus score (4.40), at a high level. Furthermore, it is also clear from students' responses to Item A3 ("Formative assessment helps me better develop my skills in inquiry-based learning activities.") that this item was also rated as having the second highest consensus score, at a mean of 4.08 and a high level. Similarly, it is also clear from students' responses to Item A6 ("Formative assessment encouraged me to think better and do inquiry-based learning activities.")

Table 7. Engagement results statistics

No	Items	Mean	SD	Level	Order
A10	Formative assessment makes me think analytically and systematically about implementing inquiry-based learning activities.	4.40	0.73	Very high	1
A3	Formative assessment helps me better develop my skills in inquiry-based learning activities.	4.08	1.34	High	2
A6	Formative assessment encouraged me to think better and do inquiry-based learning activities.	4.07	1.53	High	3
A4	My engagement is enhanced through formative assessment as I work in the inquiry-based learning activity.	4.06	1.33	High	4
A1	Formative assessment encourages students to learn independently using checklists and checklists for inquiry-based learning activities.	4.04	1.27	High	5
A8	Formative assessment encourages students to track their progress and take responsibility for their activities of inquiry-based learning.	4.01	1.52	High	6
A5	Using formative assessment provides immediate feedback that helps me improve my performance quickly.	4.00	1.36	High	7
A7	Formative assessment provides a safe learning environment that reduces students' fear of failing to perform inquiry-based learning activities.	3.99	1.33	High	8
A9	The teacher uses the results of formative assessment to adapt inquiry activities to the needs of the students.	3.93	1.10	High	9
A2	Formative assessment builds students' self-confidence by observing their gradual progress in implementing inquiry-based learning	3.84	1.27	High	10
Total		4.04	1.28	High	

Table 8. Achievement results statistics

	Levene's test for equality of variances		t-test for equality of means					
	F	Sig.	N	Mean	SD	t	df	p
Equal variances assumed Equal variances not assumed	0.002	0.962	39 (female) 46 (male)	18.31 16.65	1.44 0.87	6.526	83	0.000

that this item was rated as having the third highest consensus level, at a mean of 4.07, at a high level. Similarly, a "high" level was also obtained for items A4, A1, A8, A5, A7, and A9, with specific mean values of 4.06, 4.04, 4.01, 4.00, 3.99, and 3.93. The lowest mean (3.84) was obtained for item A2 ("Formative assessment builds students' self-confidence by observing their gradual progress in implementing inquiry-based learning"), which also came at a "high" level.

Results Related to RQ3

The mean scores and SDs of the relevant achievement test and engagement scale items were calculated for the relevant detailed gender variable under consideration. A t-test was performed to determine the significance of the mean differences. Below are the results associated with the answers to the questions, based on the gender variable.

Achievement test

Table 8 displays the findings of the t-test of the students' answers based on the variable of gender. A t-test was utilized to assess the significance of the divergences among genders in terms of achievement and engagement in chemistry topics among students of the experimental group toward the formative assessment is implemented in an IBL environment as appearing in **Table 8**. The findings in **Table 8** illustrate that the observed p-value (0.000) is less than 0.05. Thus, the test is significant at the 0.05 level, which suggests that there is a significant difference in achievement toward formative assessment is implemented in an IBL environment based on the variable of gender between students in the experimental in favor to female students.

Engagement

Table 9 displays the findings of the t-test of the students' answers based on the variable of gender. A t-test was utilized to assess the significance of the divergences among genders in terms of engagement toward the formative assessment is implemented in an IBL environment as appearing in **Table 9**. The findings in **Table 9** illustrate that the observed p-value (0.212) is larger than 0.05. Thus, the test is not significant at the

Table 9. Engagement results statistics

	Levene's test for equality of variances		t-test for equality of means					
	F	Sig.	N	Mean	SD	t	df	p
Equal variances assumed Equal variances not assumed	0.002	0.962	39 (female) 46 (male)	4.13 3.96	0.94 1.00	0.804	83	0.212

0.05 level, which suggests that there is no significant difference in engagement toward formative assessment is implemented in an IBL environment based on the variable of gender between students in the experimental

Results Related to RQ4

The interview data were analyzed through a careful and comprehensive reading of the interview transcript to identify key themes and concepts. The data were categorized using a coding technique, and the data were organized according to the interview questions, focusing on common patterns and differences between responses.

The responses of the chemistry teachers are as follows:

> "I believe that using formative assessments in an inquiry-based learning environment greatly enhances students' engagement in the learning process. It helps them think critically and formulate questions for themselves. However, I see the main challenge as the time required to prepare and design formative activities to suit this type of learning, especially with the pressure of the curriculum." (teacher 1)

> "In my experience, formative assessments are most effective when they are integrated with practical activities. Students become more interested in chemical concepts when they realize that practical performance is directly related to their assessment results. The challenge for me has been managing individual differences among students, as this requires constant adjustments to assessment tools." (teacher 2)

> "I see formative assessments as adding great value to students' learning, especially in improving their ability to analyze data and draw conclusions. One of their biggest advantages is that they provide immediate feedback that helps students understand and correct their mistakes. However, some students may not engage adequately with these methods if they are not already motivated towards inquiry-based learning." (teacher 3)

> "I find formative assessments to be a great tool to support inquiry-based learning, as they provide students with the opportunity to apply theoretical knowledge in practice and gradually improve their performance. The biggest challenge for me is to balance the implementation of these assessments and ensure that all curriculum objectives are covered on time. I also notice that students who are most engaged in the activities benefit the most." (teacher 4)

Summary of the chemistry responses

All teachers indicated the positive impact of formative assessments in improving student learning, especially in the areas of critical thinking and data analysis. However, they highlighted challenges related to time, managing individual differences, and motivating less engaged students. This reflects the need to design flexible and effective assessment tools to meet the needs of all students while ensuring that educational objectives are achieved.

DISCUSSION

The results of the study, as shown in **Table 5** and **Table 6**, showed that students who learned through the application of formative assessments in the IBL outperformed students who learned using the traditional method, as the score (mean) of the students in the experimental group (18.34) was better than the score of the students in the control group (16.02). This result can be explained by the clear impact of formative assessment on students' academic progress and competence, which includes organizing IBL (Grob et al., 2017;

Ozan & Kıncal, 2018). Students directly interact with learning experiences, deepen their understanding of meanings, and increase their practice of learning processes (Alqawasmi et al., 2024), all of which in turn increase their academic achievement. On the other hand, Feedback, as an essential component of formative assessment, is an effective element in the growth of students' academic achievement, especially when provided in a timely manner (Nicol & Macfarlane-Dick, 2006; Ruiz-Primo & Furtak, 2006). This type of feedback prompts students to reflect and adjust their learning styles, which is vital in IBL settings where students take control of their own learning. In addition, because of its inherently reflective nature and investigative characteristics (Grob et al., 2017), formative assessments align well with IBL. This alignment also helps provide a deeper learning experience where students are able to engage more rigorously with the content and are better equipped to apply knowledge in broader settings. Formative assessment has contributed to improved learning outcomes in an IBL context, as indicated by several related studies. This resonates with findings made by Grob et al. (2017), who emphasize that formative assessments support the development of scientific inquiry skills through which students can engage more deeply. Ruiz-Primo and Furtak (2006) explain that formative assessments in inquiry settings can promote reflective learning by providing cycles of feedback, which support adaptive changes and improvements to student preparation practices. In the same line, Ozan and Kıncal (2018) highlighted the benefits of structured formative assessments on IBL for improving student performance and self-regulation. Together, these studies ratify that formative assessment coupled with IBL-driven environments helps to improve the learning experience and brings about better academic performance in contrast to traditional didactic methods.

Regarding engagement, we notice from the results shown in **Table 7** that there is a clear effect of using formative assessment on increasing the interaction of the students of the experimental group during the implementation of IBL during their learning of chemistry topics, as the value of the overall arithmetic mean was 4.04 and the SD was 1.28, which indicates that the interaction of the students of the experimental group has increased significantly due to the use of formative assessment during their learning process through inquiry-based education. The researchers point out that some studies have confirmed that formative assessment enhances continuous feedback that enables students to modify their strategies and improve their effective participation during learning (Black & Wiliam, 2009). It also contributes to stimulating self-motivation for learning by enhancing the sense of achievement and developing critical thinking skills (Nicol & Macfarlane-Dick, 2006). In addition, formative assessment provides an opportunity to enhance group interaction through peer assessment activities, which helps in building an interactive learning environment that supports IBL (Ruiz-Primo & Furtak, 2007). On the other hand, some studies show that the impact of formative assessment may be limited or depend largely on how it is implemented. Bennett (2011) suggests that the effectiveness of formative assessment depends on the quality of implementation, and that poor implementation may reduce its impact on interaction. Sadler (1989) argues that students' and teachers' lack of understanding of the role of formative assessment may reduce its intended benefit. On the other hand, Taras (2005) suggests that formative assessment may not achieve the desired results if the initial interactive relationship between the teacher and students is not strong enough. Based on the above, it can be said that the use of formative assessment in IBL has great potential to enhance student engagement, but its success depends largely on the correct implementation and teachers' strategies in using it

The study also found, according to the gender variable, that the achievement of female students in the experimental group (mean = 18.31) was better than that of male students (mean = 16.65) in the same experimental group due to the use of formative assessments during the IBL environment. Difference in self-regulation between the males and females is preceding factor for this result, as Zimmerman (1989) and Sadler (1998) said that female students have more of a tendency to manage their own learning than male, which reflects on better work done either destructively or constructively performance regarding preparing assessments. Additionally, in Guo (2024) enough evidence was not found to determine if females attain better results because they respond well to feedback but according to an investigation realized by Nicol and Macfarlane-Dick (2006) their study discovered that IBL succeeded with formative assessment allowed for such a process where the then able promote more Academic success. Thus, one would argue that female students are more receptive to feedback and therefore may respond better in engaging with an inquiry-based environment (Chan et al., 2016; Orosz et al., 2023). This finding is in line with the proposition by Tirado-Olivares et al. (2021). The present findings echo those of Zimmerman (1989) and Sadler (1998), who suggest that female students are more capable than their male counterparts in self-regulating their learning, consequently leading to a better academic achievement among the former. Nevertheless, Tirado-Olivares et al. (2021) that some digital assessment tools are more predictive of male students than female student performance. The digital assessment patterns of these classes are a potential barrier for some students, as experiences in the IBL context suggest that there are gender differences in technology response. If males and females behave differently with respect to digital formative assessment tools, then we might expect different patterns according to gender (Nsabayezu et al., 2023). On the other hand, the study also concluded, according to the gender variable, that there were no statistically significant differences regarding their engagement in applying formative assessment while learning chemistry topics through IBL. The researchers believe that the lack of statistically significant differences between male and female students in terms of engagement may be due to the nature of IBL, which focuses on developing critical thinking and problem-solving skills individually or collectively, regardless of gender. This type of learning provides equal opportunities for interaction and relies on effort and actual participation rather than on personal characteristics or gender differences. In addition, the supportive and balanced educational environment may have contributed to reducing any potential impact of gender differences on the level of interaction.

Results of the chemistry teachers' perspectives on the experience of using formative assessments in an IBL environment. in an IBL environment, formative assessment plays a pivotal role in promoting critical thinking and improving students' data analysis skills. These learning environments rely on practical activities that require students to investigate information and use it effectively to solve problems. However, the effectiveness of formative assessments in this context remains marred by the challenges teachers face in implementing them effectively. This discussion aims to explore the perspectives of chemistry teachers on the experience of using formative assessments in an IBL environment, and to highlight the benefits and challenges associated with this type of assessment. Teachers' responses indicate that they see formative assessments as an effective tool for stimulating active learning and enhancing critical thinking skills, which is in line with previous research that has shown their role in improving academic performance. However, they pointed out some challenges they face, such as the need for additional time to design activities and managing individual differences among students. These challenges are consistent with what previous studies have indicated, such as Heritage (2010), which stressed the need for intensive training for teachers to enable them to design flexible assessment tools that are integrated with the curriculum. Previous studies, such as Brookhart (2008), also emphasized the importance of positive feedback in enhancing students' motivation to participate in inquiry-based activities, which was indicated by teachers in their responses. Linking activities to students' realities and interests is an effective strategy to enhance students' response and engagement with activities, which enhances the effectiveness of formative assessment. From the researcher's point of view, it can be concluded that formative assessments are an effective tool to enhance active learning, but to get the most out of them, teachers must be supported with intensive training in designing activities and provided with flexible assessment tools that are integrated with the curriculum. In addition, the use of technology to support immediate feedback should be enhanced, which helps reduce the time burden on teachers and contributes to achieving learning objectives.

However, this study faced several limitations, one of the major limitations associated with using formative assessment to improve IBL is that its effectiveness depends heavily on the quality of teacher implementation. Poor implementation or lack of understanding of assessment strategies can lead to inaccurate results or limited impact. This type of assessment also requires additional time and effort to provide personalized feedback to each student, which is a particular challenge in large, high-volume classrooms. In addition, the current study faced the limitation of a small sample size, which may affect the representativeness of the results for all students. Difficulty in generalizing the results may arise due to differences in educational contexts between schools, such as curricula and available resources, which reduces the ability to generalize the results more broadly. In addition, the difficulty of accurately measuring engagement may be a major limitation, as it is difficult to determine the actual level of engagement of students in IBL using standardized measurement tools.

IMPLICATION OF THE STUDY

The use of formative assessment in IBL has several important implications that can contribute to improving the educational process. It helps teachers develop more effective teaching strategies that support critical thinking and students' engagement with scientific topics. In addition, formative assessment enhances students' motivation by providing continuous feedback, which encourages them to actively participate and gain a deeper understanding of scientific concepts. This type of assessment also allows for differentiation in education, as teachers can meet the needs of different students by customizing activities and tasks to suit their abilities. Moreover, formative assessment contributes to improving the classroom environment by creating an interactive learning space that encourages dialogue, discussion, and effective inquiry between students and teachers.

CONCLUSION

This study explored the role of formative assessment in supporting students' achievement and engagement in chemistry within an IBL environment at the secondary-school level. The findings suggest that formative assessment can play an important role in helping teachers follow students' understanding during the learning process and provide feedback that supports learning. When formative assessment is integrated into IBL, it can contribute to creating a more interactive learning environment in which students participate more actively and develop a deeper understanding of chemistry concepts. The results of this study also highlight the value of combining formative assessment with inquiry-based instruction in chemistry classrooms. Such integration allows teachers to monitor students' progress more effectively and to adjust instruction based on students' needs during the learning process. In addition, the teachers' perspectives collected in this study provide practical insights into how formative assessment strategies can be implemented during IBL activities. Overall, this study adds to the growing research on formative assessment and IBL in science education by focusing specifically on secondary-school chemistry classrooms. By examining students' achievement, engagement, and possible gender differences, the study provides a broader understanding of how formative assessment can support students' learning in inquiry-based environments.
Future research may further examine how different formative assessment strategies can be applied in various science learning contexts and how these practices influence students' learning over longer periods of time.

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