

# Effect of physics education technology-supported instruction on high school students' understanding of physics

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## ABSTRACT

This study examined the effectiveness of a guided inquiry-based instructional method, interactive simulation instruction approach (ISIA), which integrates physics education technology simulations on ninth-grade students' comprehension of sound waves. The study was conducted at Damot No. 1 High School in Finoteselam Town, Ethiopia, and compared conventional instruction and ISIA combined with collaborative group work. A quasi-experimental pre-/post-test design was employed. Students' conceptual understanding was assessed using adapted items from the sound achievement test, mechanical waves conceptual survey, and sound concept inventory instrument. Score differences across groups were examined using descriptive statistics and an independent samples t-test. According to the results, students who received instruction using ISIA outperformed their classmates in the conventional group on the post-test. These findings imply that students' conceptual understanding of sound wave phenomena might be significantly enhanced by integrating interactive simulations into physics education.

**Keywords:** conceptual understanding, interactive simulation instruction approach, physics education research, physics education technology, sound wave

## INTRODUCTION

Developing a solid conceptual understanding is the central goal of science education, particularly in physics, where abstract concepts underpin the explanation of natural phenomena. Conceptual understanding enables students to relate abstract ideas to real-world experiences, apply knowledge in a transferable manner, and solve new issues logically. However, research indicates that many secondary school students complete physics instruction without achieving meaningful conceptual understanding and instead rely heavily on algorithms and mathematical equations (Docktor et al., 2015). Consequently, students find it difficult to answer qualitative questions that require conceptual reasoning rather than procedural recall (Coetzee & Imenda, 2012).

As a foundational science that investigates natural phenomena through a variety of theories, physics also poses challenges because of students' misconceptions and their inability to understand fundamental concepts like mechanics, electricity, magnetism, thermodynamics, waves, and optics (Daud et al., 2015). In addition, physics is involved in many aspects of daily life, and students frequently form certain ideas about the subject through their experiences, but these ideas may not always align with scientific realities; these counterintuitive experiences result in misconceptions (Özkan & Umdu Topsakal, 2020; Umar et al., 2021). Misconceptions account for a significant portion of students' failure in physics classes and correcting them is crucial to effective instruction (Ozkan, 2013; Sozen & Bolat, 2011). Therefore, failing to appropriately address misconceptions hinders effective physics instruction (Eshetu & Alemu, 2018; Hrepic, 2011; Umar et al., 2021).

Our understanding of both classical and modern physics depends on our ability to comprehend sound as a wave phenomenon. A strong grasp of sound as a wave, which is taught in high school, is essential for students to understand later physics courses (Benzen & Bayrak, 2020). However, despite their significance, sound and wave ideas are often taught in schools with little focus (Hrepic et al., 2010). Given this neglect and persistent misconceptions, targeted educational initiatives are required (Eshach, 2014; Eshach et al., 2016).

Understanding sound waves, a common yet complicated physical phenomenon, is one area of particular concern (Aygun & Hacıoglu, 2022). Sound is often taken for granted. Nevertheless, it is a complex phenomenon with fundamental attributes that are not easily understood (Kanyesigye et al., 2022; Volfson et al., 2022; Yusof et al., 2022). Misconceptions such as the belief that sound requires an unobstructed passage or travels as an entity with dimensions are common among students (Coetzee & Imenda, 2012; Eshach et al., 2018; Tumanggor et al., 2020). These misconceptions also include ideas such as the relation between frequency and pitch or amplitude and loudness, and speed in the propagation of mechanical waves like sound waves (Tumanggor et al., 2020).

Thus, sound continues to be a difficult concept for students to fully understand, even though it is present in everyday life (Azahra et al., 2024; Caleon & Subramaniam, 2010; Eshach, 2014; Hrepic et al., 2010). These false conceptions are pervasive and strong at all educational levels (Hrepic, 2011).

Although it can be challenging to see the medium that sound travels through, applying the proper material requires a thorough understanding of sound waves. This makes it more difficult to differentiate between the medium's mobility and the motion of a wave (Sözen & Bolat, 2016). Students must undergo an ontological shift to visualize sound propagation and the abstract nature of sound transmission (Chi, 2013; West & Wallin, 2013).

Students' comprehension of sound waves has not received enough attention from research on alternative conceptions and conceptual transformation (Caleon & Subramaniam, 2010). Compared to other physics topics like force, light, and electricity, sound is misunderstood more frequently (Ozkan, 2013; Tongchai et al., 2011), and there is a dearth of research on the subject in the literature on scientific education (Ladachart & Nashon, 2010). Most research has focused on University students rather than high school students (Eshach et al., 2016), and most have been conducted in Western contexts (Eshach, 2014).

To enhance students' conceptual knowledge of sound waves, particularly at the microscopic level, computer simulations from physics education technology (PhET) are utilized as cognitive aids (Aslan & Demircioğlu, 2014; Agyei & Agyei, 2021; Gunhaart & Srisawasdi, 2012). By actively participating in material and drawing conclusions from their interactions, students can effectively deepen their understanding, a process well supported by interactive computer simulations (Azhar et al., 2024; Ogegbo & Ramnarain, 2022).

One significant gap in technology-aided learning research is understanding how simulations support students in developing realistic science practices. There is also limited literature on how students perceive simulations as teaching tools (Peffer et al., 2015). While interactive computer simulations with rich images and visualizations are a recent educational addition, little research exists in developing countries (Harahap et al., 2025). Research using interactive PhET simulations to improve conceptual understanding of sound waves in combination with scaffolded inquiry-based collaborative learning is scarce. Banda and Nzabahimana (2021) reviewed 31 publications physics quasi-experimental studies and emphasized the need for more research on group and collaborative learning strategies supported by PhET simulations.

There has been little study on the combined efficacy of interactive simulations, scaffolded collaborative inquiry-based learning, despite their acknowledged promise independently, particularly in high school physics (Banda & Nzabahimana, 2021). To fully explore the pedagogical possibilities of merging computer-based simulations with inquiry-based education, more research across multiple student populations and various contexts is recommended (Fan et al., 2018).

The efficacy of an inquiry-based interactive simulation instruction approach (ISIA) containing PhET simulations was examined in a study by Fan et al. (2018), which is consistent with the current research. Compared to previous research on Newton's laws of motion, this study is very different. Sound waves include distinct physics ideas and could be more difficult for pupils to understand than Newton's Laws of Motion. This results in a gap in the research. Furthermore, because the current study was conducted in Ethiopia, which can have different student profiles and educational resources than the prior study, which was conducted in China, the geographical setting also serves as a differentiating factor. This offers a chance to investigate how these variations in subjects and settings impact students' conceptual knowledge levels and how well the ISIA works to address conceptual understanding of various materials.

The ISIA is a promising strategy that dispels students' intuitive understandings and promotes collaborative group inquiry learning. This approach aligns with the zone of potential development (ZPD), Vygotsky (1978), and scaffolding theory (Quintana et al., 2018), and the conceptual change model (CCM) (Posner et al., 1982). ISIA encourages conceptual conflict, scaffolding, and ZPD (Fan, 2015; Fan et al., 2018). This study follows the social and cognitive constructivist theoretical frameworks.

Conceptual change, which happens when students' preconceived notions about the world collide with scientific knowledge, is a fundamental idea in inquiry-based learning. Posner et al. (1982) claim that when students realize their existing concepts are insufficient and the new idea is more plausible, intelligible, and fruitful, they go through a conceptual change. Fan et al. (2018) outlined an inquiry method of instruction on this concept by fusing Vygotsky's (1978) ZPD and scaffolding framework theories (Quintana et al., 2018) with Posner et al.'s (1982) CCM to create the ISIA for conceptual understanding in physics. ISIA is divided into five stages:

1. **Elicitation and clarification:** Through conversation, students investigate different ideas and clear up any misunderstandings, laying the foundation for a conceptual change.
2. **Prediction and implication:** Based on what they anticipate happening in interactive simulations, students explain their initial concepts, offer predictions, and suggest possible outcomes.
3. **Testing prediction:** Using PhET simulations, students evaluate the viability of various concepts and test their predictions, offering an interactive learning experience.
4. **Elucidation and linking:** Through presentations and teacher-student conversations, students clarify their conclusions and make connections between their findings and accepted scientific principles.
5. **Metacognitive assessment and further testing:** Lastly, students assess their education, pinpoint their strengths and weaknesses, and apply the inquiry-based learning paradigm to practical situations. This last stage promotes continued introspection and in-depth learning.

Despite its potential, research on PhET simulations shows mixed results. Some studies report positive impacts on students' understanding, motivation, and engagement (Almadrones & Tadifa, 2024; Fan, 2015; Fan et al., 2018; Najib et al., 2022; Pranata, 2024; Suleman et al., 2017). While others find minimal difference before and after simulation use (Geelan et al., 2014; Rosali, 2020;

Yunzal & Casinillo, 2020). These discrepancies may relate to the level of interaction or the design of visualizations. To produce high-quality evidence on their effectiveness, better-designed simulations and careful pedagogical planning are needed (Geelan et al., 2014). PhET simulations, when integrated with inquiry-based teaching like ISIA, may enhance students' creative thought and conceptual understanding.

Moreover, students cannot effectively learn physics independently through pure discovery teaching (Alfieri et al., 2011; Aquines Gutiérrez et al., 2022). Overly supervised activities also hinder deep learning. Strategies that balance instructional guidance and cognitive engagement best support constructivist learning (Honomichl & Chen, 2012). Students need the appropriate scaffolding to develop a conceptual model (Alanazi et al., 2024; Holmes et al., 2014), especially in diverse classrooms with reluctant learners and limited prior experience (Aquines Gutiérrez et al., 2022; Zacharia et al., 2015). This study uses implicit guided inquiry supported by PhET simulations, worksheets, peer collaboration, teacher guidance, and scientific language (Fan et al., 2018; Perkins et al., 2012).

Given PhET's mixed results, the study explores the impact of scaffolded interactive PhET simulations on high school students' conceptual understanding of sound waves in the Ethiopian context. Physics education in Ethiopia emphasizes numerical calculations and rule applications (Halim & Lestari, 2019), but this approach does not foster deep conceptual understanding (Getinet, 2012; Xie et al., 2021). Misconceptions persist due to rote learning and a focus on mathematical procedures (Aragaw et al., 2022). These methods hinder learning and reduce students' interest (Alemu et al., 2021; Batlolona & Jamaludin, 2024; Halim & Lestari, 2019).

The quality of high school education in Ethiopia is low. National school-leaving exams show only 3.3% and 3.2% of students scoring above 50% in 2022 and 2023, respectively (Tadesse et al., 2024). These results highlight notably low learning outcomes (Awayehu, 2017; Tefera et al., 2017; Worku et al., 2018). Ethiopian students consistently perform poorly in physics (Goshu & Woldeamanuel, 2019; Hamelo, 2016).

Contributing factors include inappropriate teaching methods, limited resources, the subject's inherent challenges, and inadequate laboratory facilities (Assefa, 2020; Chala et al., 2020; Goshu et al., 2024; Liyew et al., 2017). Among these, traditional teaching methods take the lead. This method does not improve students' understanding (Mihiretie, 2023; Sbhatu, 2021), and a lack of real-world examples reinforces misconceptions (Munandar et al., 2023). Teachers often favor textbook problems over contextual learning (Batlolona & Jamaludin, 2024; Munandar et al., 2023). Despite national efforts in science and education in general, students continue to face major difficulties in physics (Joshi & Verspoor, 2013; NRC, 2013). To engage students effectively, physics education in Ethiopia should use simulations and multimedia to teach abstract concepts linked to real-life experience (Mandado, 2017; Perkins et al., 2014). PhET simulations offer dynamic, interactive learning that addresses conceptual difficulty (Gebru, 2023; Harahap et al., 2025; Munandar et al., 2023).

This study aims to solve students' difficulties in learning physics through the ISIA. It seeks to improve performance in sound wave physics, addressing misconceptions and enhancing conceptual understanding.

## MATERIALS AND METHODS

This study employed a non-randomized pre- and post-test quasi-experimental design. As it was not possible to randomly assign learners to groups or employ random sampling within the current school curriculum, a quasi-experimental option was adopted (Capili & Anastasi, 2024). The study was conducted in a typical classroom setting to prevent disruptions to the teaching process and to enable a methodical comparison of learning outcomes (Sani, 2017).

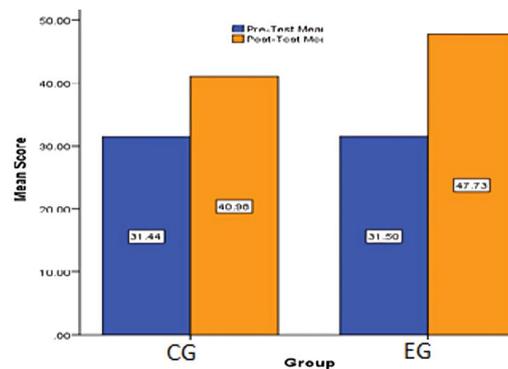
The sample consisted of 76 (29 males and 47 females) ninth-grade students from two intact classrooms, randomly assigned to either the experimental group (EG) ( $n = 41$ ) or the control group (CG) ( $n = 35$ ).

A three-day training program was offered to participating teachers to reduce the impact of outside variables, such as teacher variations. The utilization of PhET simulations, inquiry-based teaching techniques, inquiry lesson planning, and strategies for clearing frequent student misconceptions were highlighted in this training. Additionally, the participating teachers were required to prepare a lesson plan according to the teaching methods, and classroom observations were conducted to check the implementation of each method by participating teachers and the researcher for consistency.

To assess students' understanding of sound concepts, selected items were adapted from the Sound Achievement Test (SAT) (Sözen & Bolat, 2016), the sound concept inventory instrument (Eshach, 2014), and the mechanical waves conceptual survey (Tongchai, 2011). These items were reformatted into a two-tier sound concept test (SCT), consisting of 28 multiple-choice questions (first tier) with accompanying justification prompts (second tier). Before the main study, a pilot test was conducted to confirm the test's reliability, and its content and face validity were reviewed by two experts, one from a high school and the other from a teacher education college. The SCT's reliability, determined by using the Kuder-Richardson formula 20, yielded a coefficient of 0.847, which is high.

The SCT was administered as a pre-test to both groups at the start of the study. A 10-week instructional intervention followed (9 April 2025-20 June 2025) covering topics such as sound production, sound propagation, frequency/pitch, amplitude/loudness, speed of sound, sound energy, musical instruments, and properties of sound waves.

Conventional education in line with typical Ethiopian classroom procedures was given to the CG. On the other hand, an inquiry-based ISIA was used to teach the EG. This includes structured PhET simulations, inquiry worksheets, collaborative peer work, teacher guidance, and integration of scientific language. The structured PhET simulations in this study mainly consists of particle vibration (air), wave motion, density (air), frequency, and amplitude. The inquiry worksheet guides students to elicit, predict, test



**Figure 1.** Descriptive statistics of pre- and post-test mean scores by group (Source: Authors' own elaboration, using SPSS software, version 23)

**Table 1.** Descriptive statistics of pre- and post-SCT scores by group

Group	N	Pre-SCT score				Post-SCT score			
		M	SD	Skewness	Kurtosis	M	SD	Skewness	Kurtosis
CG	35	31.44	5.11	0.81	0.37	40.98	5.49	0.60	-0.26
EG	41	31.50	6.27	0.45	-0.72	47.73	7.05	-0.05	-0.60

**Table 2.** Independent samples t-test of pre-SCT scores between groups

	Levene's test		t-test for equality of means					Effect size (Cohen's d)		
	F	Significance	t	df	Significance	MD	SE		95% CI	
									Lower	Upper
Pre-test: Equal variance assumed	2.10	0.15	0.05	74	0.960	0.06	1.33	-2.58	2.71	0.01

Note. SE: Standard error & MD: Mean difference

prediction, elaborate and link, and metacognitive analyze and further test using the PhET simulations. The teacher uses scientific language regularly for the correct terminology, like high pitch/high frequency, low pitch/deep sound/low frequency, loud sound/high amplitude, soft sound/low amplitude, and so on. The intervention was delivered to the physics laboratory by a single trained teacher every week, assisted by a researcher.

Each EG (four students) received the inquiry worksheets a week in advance along with access to the relevant simulation via the PhET simulation website (<https://phet.colorado.edu/en/simulation/sound>), allowing students to explore the concepts independently using their cellphones. The study implemented the ISIA, which integrated PhET simulations. Following the intervention, the SCT was re-administered to both groups as a post-test. Pre- and post-test data were analyzed using SPSS and are presented in the subsequent tables and figures.

## RESULTS

This section presents the findings based on the administration of the SCT to each of the CG and EG. **Figure 1** displays the mean (M) SCT scores for both the pre- and post-test across the two groups. Both groups demonstrated significant improvement in their post-test performance compared to their pre-test scores (CG: +9.54, EG: +16.23). Descriptive statistics from **Figure 1** indicate slight variations in the M SCT pre-test scores between the two groups. To determine whether these differences were statistically significant, appropriate inferential statistical tests were conducted. As illustrated in **Table 1**, descriptive statistics, including Skewness, Kurtosis, M, and standard deviation (SD), were calculated for both groups' pre- and post-test SCT scores.

As shown in **Table 1**, the pre- and post-test SCT scores met the assumptions of normality, with skewness  $< \pm 2$  and kurtosis  $< \pm 7$  values falling within the acceptable range (Demir, 2022; Matore & Khairani, 2020). Additionally, **Table 2** presents the result of Levene's test for equality of variances, which confirmed that the assumption of equal variances was not violated for the pre-test scores ( $F [1, 74] = 2.1, p = .15$ ).

After checking the assumptions of normality and homogeneity of variance, an independent samples t-test was conducted to compare the pre-test scores between the CG ( $M = 31.44, SD = 5.11$ ) and the treatment group ( $M = 31.50, SD = 6.27$ ). The results indicated no statistically significant difference ( $t [74] = .05, p = .96$ ). The mean difference was 0.06 ( $SE = 1.33$ ) with a 95% confidence interval ranging from -2.58 to 2.71. Cohen's d was approximately .01, indicating a negligible difference between groups at pre-test.

These results suggest that both groups had nearly equivalent baseline conceptual understanding of sound wave concepts, and thus the null hypothesis of no significant difference at pre-test was retained.

Based on the pre-test analysis, the EG received instruction through the ISIA, while the CG continued with conventional teaching methods. Following the intervention, post-SCT descriptive statistics scores were analyzed and are presented in **Table 1**. Skewness and kurtosis values for groups fell within the acceptable range  $< \pm 2$  and  $< \pm 7$ , respectively (Demir, 2022; Matore & Khairani, 2020), indicating that the assumption of normality was satisfied.

**Table 3.** Independent samples t-test of post-SCT scores between groups

	Levene's test		t-test for equality of means					Effect size (Cohen's d)		
	F	Significance	t	df	Significance	MD	SE		95% CI	
									Lower	Upper
Post-test: Equal variance assumed	3.08	0.08	4.60	74	0.000	6.75	1.47	3.82	9.68	1.07

Note. SE: Standard error & MD: Mean difference

**Table 4.** Test of gender equivalence for pre- and post-test mean scores

Test	Gender	N	M	SD	Levene's test		t-test for equality of means			
					F	Significance	t	df	Significance	
Pre-test	Male	29	32.15	5.49	Pre-test	1.500	0.24	0.81	74	0.42
	Female	47	31.05	5.89						
Post-test	Male	29	46.00	7.03	Post-test	0.003	0.96	1.31	74	0.19
	Female	47	44.00	7.24						

As shown in **Table 3**, Levene's test for homogeneity of variance was not significant, yielding ( $F [1, 74] = 3.08, p = .08$ ), confirming that the assumption of equal variances was met. Accordingly, an independent samples t-test was conducted to examine the difference in post-SCT M scores between the CG and EG.

As presented in **Table 3**, the results revealed a statistically significant difference in M scores: CG ( $M = 40.98, SD = 5.49$ ) and treatment group ( $M = 47.73, SD = 7.05$ ); ( $t [74] = 4.60, p < .001$ , two-tailed). The mean difference was 6.75 (standard error = 1.47), with a 95% confidence interval ranging from 3.82, 9.68. Cohen's d was approximately 1.07, indicating a large effect size and a substantial difference in conceptual understanding between the two groups after the intervention.

These results demonstrate that the EG outperformed the CG significantly. Therefore, the null hypothesis was rejected. The findings confirm that the ISIA was a key factor contributing to the improvement in the EGs' post-test performance.

As shown in **Table 4**, an independent samples t-test was conducted to determine if gender differences in pre- and post-test scores were significant. The assumption of equal variance was satisfied with the pre-test scores, shown by the non-significant results of the Levene's test for equality of variances ( $F [1, 74] = 1.50, p = .24$ ). Males ( $M = 32.15, SD = 5.49$ ) and females ( $M = 31.05, SD = 5.89$ ) did not differ significantly ( $t [74] = 0.81, p = .42$ ).

Levene's test for equality of variances for the post test results also showed no significant difference ( $F [1, 74] = .003, p = .96$ ). Males ( $M = 46.00, SD = 7.03$ ) and females ( $M = 44.00, SD = 7.24$ ) did not differ significantly ( $t [74] = 1.31, p = .19$ ). These findings imply that neither pre-test nor post-test scores were statistically impacted by gender.

## DISCUSSION

This study examined the effectiveness of an inquiry-based ISIA on 9<sup>th</sup> grade students' conceptual understanding of sound waves in physics, as measured by the SCT, in comparison to conventional instruction.

An independent samples t-test revealed no statistically significant difference in pre-test scores between the CG and EG,  $t (74) = .05, p = .96$ . The mean difference of 0.06 (95% confidence interval [CI] -2.58 to 2.71) and a negligible effect size (Cohen's  $d \approx 0.01$ ), indicating that both groups began the study with similar baseline knowledge.

In contrast, post-test results showed a significant difference between the two groups, with the EG outperforming the CG: ( $t [74] = 4.60, p < .001$ , two-tailed). The mean difference was 6.75 (95% CI 3.82 to 9.68) and the effect size was large (Cohen's  $d \approx 1.07$ ), demonstrating a substantial improvement in conceptual understanding among students exposed to ISI (Cohen, 2013). Based on the results, the null hypothesis was rejected. The baseline equivalence between the CG and EG and the satisfaction of statistical assumptions support the internal validity of the findings and indicate that the observed post-test differences can be attributed to the instructional intervention rather than pre-existing group differences (Creswell & Creswell, 2018). Since sound wave concepts are dynamic and abstract by nature, typical conventional instruction might not be sufficient to clear up students' misconceptions. ISIA likely facilitated conceptual change by making invisible processes visible and promoting active engagement, which is central to constructivist learning theory (Mayer, 2009; Piaget, 1970).

These results are consistent with previous studies that highlight the benefits of inquiry-based learning environments, particularly when enriched with simulations that encourage active student engagement (Almadrones & Tadifa, 2024; Fan et al., 2018; Najib et al., 2022; Suleman et al., 2017). Such approaches have been shown to foster deeper conceptual understanding by supporting students in making meaningful connections between scientific concepts and visual representations.

However, not all prior research has reported large learning gains from simulations. Some studies (Geelan et al., 2014; Rosali, 2020; Yunzal & Casinillo, 2020) noted only modest improvement. These limited effects may be due to reduced opportunities for students to engage interactively with simulations or to suboptimal instructional design. This highlights the importance of high-quality visual tools with pedagogically sound teaching strategies that promote inquiry and reflection. However, it's possible that these trials limit the amount of interaction that students could have with the representations. Therefore, the main factors influencing the efficacy of interactive simulations to provide high-quality evidence of the usefulness of visuals for conceptual development were the use of better-designed representations and careful attention to the pedagogy around them. Another limitation may be the choice of the right type of simulations used. The PhET simulation provided by the University of Colorado Boulder is easy to use and offers a clear visualization.

Overall, the results support the notion that, with the right pedagogy, an inquiry-based interactive simulation instruction strategy can greatly enhance learning outcomes.

In sum, the findings of this study support the effectiveness of a well-structured inquiry-based ISIA in enhancing students' conceptual understanding. With thoughtful implementation, such approaches hold strong potential to improve physics education outcomes at the high school level.

## CONCLUSION

The study demonstrated that an inquiry-based ISIA significantly enhanced students' conceptual understanding of sound waves in physics. Students in the EG, who engaged with structured PhET simulations supported by inquiry worksheets, cooperative peer learning, instructor guidance, and scientific language, demonstrated the greatest conceptual changes.

The ISIA approach proved effective in helping students construct accurate mental models of abstract sound-related concepts such as air density, the vibration of air particles, frequency/pitch, amplitude/loudness, speed of sound, sound production, and sound transmission. The integration of inquiry-based learning with interactive simulations encouraged students to learn collaboratively, independently, and through guided instruction.

These findings suggest that combining PhET simulations with inquiry-driven scaffolding through structured worksheets, peer interaction, and teacher support can greatly enhance the effectiveness of teaching abstract physics concepts. Educators are encouraged to adopt such instructional strategies to foster deeper understanding and engagement among students. Furthermore, physics textbook authors and curriculum designers are urged to incorporate inquiry-based interactive simulation methods into educational materials to support widespread adoption in classroom settings.

While the results are promising, it is vital to note this study's limitations. particularly, the relatively small sample size, which may limit generalizability. Nevertheless, the findings affirm that ISIA, when well-implemented, can substantially improve high school students' conceptual comprehension of sound wave phenomena.

In summary, this study highlights the pedagogical value of integrating inquiry-based methods with interactive simulations, offering a compelling approach to teaching complex scientific concepts in physics classrooms.

**Author contributions:** **AKG:** conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing - original draft, writing - review & editing, visualization, project administration; **ALS:** methodology, validation, formal analysis, supervision, writing - review & editing; **NGD:** conceptualization, methodology, supervision, writing - review & editing, project administration. All authors sufficiently contributed to this study and agreed with the results and conclusions.

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**Ethical statement:** The authors stated that the study was reviewed and approved by the Department of Physics, College of Natural Sciences, Jimma University, on 11/06/2017 E.C. (Approval Code: Phys/160/2025). Informed consent was obtained from all participants prior to their involvement in the study. Participants were fully informed about the purpose of the research, the voluntary nature of their participation, and their right to withdraw at any time without any consequences.

**AI statement:** The authors stated that to enhance clarity, coherence, and overall quality, this work was refined using AI-assisted tools, including Scribbr's paraphrasing tool and the free version of ChatGPT-4.0. Scribbr was used to paraphrase the initial draft to improve clarity and structure, while ChatGPT provided suggestions for language refinement and stylistic improvement. All AI-generated suggestions were carefully reviewed, verified, and edited by the author, who retains full responsibility for the final content.

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

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

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