Secondary School Students' Self-Reported Visualization Skills and Conception of Learning through PhET Simulations in Learning Physics: A Correlational Study

Yoagalaksmi[1], Racheal Rebecca[2]

[1]SMK Pasir Gudang 3, Johor, Malaysia

[2]SMK Heng Ee, Penang, Malaysia

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ABSTRACT

PhET interactive simulations provide visual and interactive representations that may support students in exploring abstract concepts in Physics. This study investigated Form 4 secondary school students' self-reported visualization skills, their conception of learning through PhET simulations and the relationship between these variables. A quantitative correlational research design was employed, involving 60 Form 4 Physics students from one secondary school in Malaysia. Data were collected using a structured questionnaire comprising a demographic section and two main sections assessing self-reported visualization skills and conception of learning through PhET simulations. The 26 construct items were measured on a four-point Likert scale. The first section assessed self-reported visualization skills across four constructs: analyzing visual information, describing Physics concepts visually, illustrating Physics scenarios and outlining key concepts visually. The second section assessed conception of learning through three constructs: understanding abstract concepts, cognitive engagement and personal perception of learning. Descriptive statistics, including means and standard deviations, were used to summarize students' responses, while Pearson's correlation coefficient was employed to examine the relationship between the two variables. The findings revealed that mean scores for self-reported visualization skills ranged from 3.09 to 3.55, while mean scores for conception of learning ranged from 3.07 to 3.43, indicating high to very high levels across the measured constructs. Pearson's correlation analysis revealed a weak positive, statistically significant relationship between self-reported visualization skills and conception of learning through PhET simulations ($r = .320$, $p = .013$, $n = 60$). This suggests that students who reported higher visualization skills tended to report a more positive conception of learning through PhET simulations. The findings provide insight into the relationship between students' self-reported visualization skills and their conception of learning in Physics. Future research could incorporate direct assessments of visualization skills and larger, more diverse samples to further examine this relationship in Physics education.

Keywords: PhET simulations, visualization skills, conception of learning, Physics education, secondary school students

INTRODUCTION

Background of Study

Physics is an important discipline in science education as it develops students' critical thinking, logical reasoning and problem-solving abilities (Abdullah et al., 2023). However, students often face difficulties understanding abstract Physics concepts, such as forces, energy transformations and electric fields, because these phenomena cannot always be observed directly (Mayer et al., 2002; Ng et al., 2023). Understanding such concepts requires students to interpret visual information and develop mental representations of physical processes (Höffler et al., 2007). Therefore, visualization skills are essential in helping students interpret scientific representations and understand abstract Physics concepts (Mnguni, 2014; Sundari et al., 2020).

Traditional instructional approaches that rely heavily on textual explanations, mathematical procedures and static diagrams may limit opportunities for students to explore dynamic physical phenomena (Finkelstein et al., 2005).

These limitations may contribute to difficulties in interpreting scientific representations and developing conceptual understanding (Singh, 2008; Turgut et al., 2011). In the Malaysian educational context, challenges related to instructional practices and the integration of interactive technologies may further influence students' learning experiences (Khasawneh et al., 2023; Lee et al., 2022; Rahman et al., 2020). Interactive learning resources, such as PhET simulations, offer opportunities for students to manipulate variables and observe simulated outcomes, supporting the exploration of abstract Physics concepts (Gupta et al., 2014)

In addition to visualization skills, students' conception of learning is relevant to understanding their learning experiences. Conception of learning refers to students' beliefs and perceptions regarding the nature and process of learning, including whether learning is viewed as memorization or as an active process of understanding and connecting ideas (Marton et al., 1993; Entwistle et al., 2004). Although PhET simulations provide interactive visual representations, students' self-reported visualization skills and their conception of learning represent distinct aspects of learning that warrant investigation. Examining the relationship between these variables may provide insights into students' reported experiences with PhET-supported Physics learning, particularly among secondary school students in Malaysia.

Statement of Problem

Visualization skills are important in Physics learning, as students need to interpret visual representations and understand abstract concepts. However, students may experience difficulties in these areas, particularly when learning relies on traditional instructional approaches (Khasawneh et al., 2023; Yusof et al., 2024). PhET simulations provide opportunities to explore Physics concepts through dynamic visual representations (Tan et al., 2023; Odum et al., 2021). Through these visual interactions, students may develop perceptions of how they understand abstract concepts, engage with learning activities and experience learning through simulations (Chua et al., 2021). Therefore, visualization skills may be associated with students' conception of learning through PhET simulations. However, the relationship between these two constructs remains insufficiently explored, particularly among secondary school students in Malaysia. Addressing this gap, the present study examines students' self-reported visualization skills, their conception of learning through PhET simulations and the relationship between these variables.

Research Objectives

The key objectives guiding this research are as follows:

1. To determine the self-reported visualization skills of secondary school students when learning Physics through PhET simulations.

2. To identify secondary school students' conception of learning through PhET simulations in Physics.

3. To investigate the relationship between students' self-reported visualization skills and their conception of learning through PhET simulations.

Research Questions

1. What is the self-reported visualization skills of secondary school students when learning Physics through PhET simulations?

2. What is secondary school students' conception of learning through PhET simulations in Physics?

3. Is there a significant relationship between students' self-reported visualization skills and their conception of learning through PhET simulations?

Significance of Study

This study provides insights into students' self-reported visualization skills and conception of learning through PhET simulations in Physics education. The findings may help Physics teachers understand students' perceived visualization skills and conception of learning, thereby informing the integration of interactive simulations into

teaching practices. The study may also provide educational policymakers and curriculum planners with context-specific insights into the use of PhET simulations in Malaysian secondary school Physics education. Furthermore, the findings may serve as a basis for future research on the relationship betw-

een students' self-reported visualization skills and their conception of learning through PhET simulations.

Operational Definition

- **PhET Simulations:** Interactive digital simulations used to represent physical phenomena and allow students to explore Physics concepts by manipulating variables and observing simulated outcomes.
- **Visualization Skills:** Students' self-reported abilities to analyze visual information, describe Physics concepts visually, illustrate Physics scenarios and outline key concepts visually when learning through PhET simulations.
- **Conception of Learning:** Students' reported perceptions of learning through PhET simulations, including understanding abstract Physics concepts, cognitive engagement with simulations and personal perceptions of learning through PhET simulations.

LITERATURE REVIEW

Theoretical Framework

This study is underpinned by Mental Model Theory and constructivist learning theory. Mental Model Theory explains how learners construct internal representations to understand and reason about phenomena that may be difficult to observe directly (Johnson-Laird, 1983). In Physics education, these mental representations are important for interpreting visual information and understanding abstract concepts (Singh, 2008; Turgut et al., 2011). PhET simulations provide interactive visual representations that allow students to explore physical phenomena and observe the outcomes of manipulating variables (McKagan et al., 2008). This theoretical perspective supports the examination of students' self-reported visualization skills, including their ability to analyze visual information, describe Physics concepts visually, illustrate Physics scenarios and outline key concepts visually.

Constructivist learning theory emphasizes that learners actively develop understanding through experience and interaction with their learning environment. Vygotsky's (1978) concept of the Zone of Proximal Development further highlights the role of guidance and support in facilitating learning. In the context of PhET-supported Physics learning, interactive simulations provide opportunities for students to explore concepts and engage with visual representations. These theoretical perspectives provide a basis for examining students' conception of learning, particularly their reported understanding of abstract Physics concepts, cognitive engagement and personal perceptions of learning through PhET simulations. Together, the theories inform the investigation of the relationship between students' self-reported visualization skills and their conception of learning in Physics.

Visualization Skills and Conception of learning Through PhET Simulations

Visualization is an important cognitive skill in Physics education, enabling students to interpret visual information, construct mental representations and understand abstract phenomena (Sundari et al., 2020). Mental model theory explains how learners develop internal representations to understand and predict how systems behave (Moray et al., 1999). However, difficulties in interpreting visual and symbolic representations may hinder students' conceptual understanding (Mnguni, 2014). PhET simulations provide dynamic visual representations that allow students to manipulate variables and observe physical processes. These interactive experiences may help students develop their understanding of abstract Physics concepts. Previous studies have highlighted the potential of simulations to support conceptual understanding and student engagement (Rutten et al., 2012; Suyatna et al., 2021).

Conception of learning refer to students' beliefs and perceptions about the nature and process of learning, ranging from memorization to meaningful understanding (Marton et al., 1993; Entwistle et al., 2004). Interactive simulations provide opportunities for exploration and observation, potentially encouraging students to engage actively with learning rather than passively receive information (Gupta et al., 2014). Visualization skills and

conception of learning represent distinct but potentially related aspects of students' learning experiences. While visualization skills concern students' self-reported ability to interpret and represent Physics information visually, conception of learning reflect their perceptions of understanding and engagement.

However, the relationship between these variables remains insufficiently explored among Malaysian secondary school Physics students. Therefore, this study examines students' self-reported visualization skills, their conception of learning through PhET simulations, and the relationship between these variables.

Comparative Analysis of Previous Studies

Previous studies have examined interactive simulations in Physics education from different perspectives, including visualization skills, conceptual understanding, student engagement and attitudes towards learning. Table 1 summarizes selected studies relevant to the present research.

Table 1. Comparison of Previous Studies on Interactive Simulations in Physics Education

Author(s)	Focus of study	Key contribution and relevance
McKagan et al. (2008)	PhET simulations in Physics education	Examined the development and educational use of interactive simulations, providing a foundation for understanding their role in supporting students' exploration of Physics concepts.
Srisawasdi and Kroothkeaw (2014)	Visualization skills in electric circuits	Developed the DCEC–ViSIT instrument to assess students' visualization skills, highlighting the importance of examining visualization as a distinct aspect of Physics learning.
Ukozor et al. (2016)	Simulation-based learning, scientific skills, and attitudes	Investigated students' scientific skills and attitudes in simulation-supported learning, providing a basis for examining students' perceptions of learning through simulations.
Muhamad et al. (2020)	Malaysian students' attitudes towards Physics learning in a virtual environment	Provided context for understanding students' attitudes and experiences in technology-supported Physics learning.
Tan et al. (2023)	Simulations and misconceptions about energy conservation	Examined the use of simulations to address conceptual difficulties, illustrating their relevance to understanding abstract Physics concepts.

The studies in Table 1 share a common interest in improving Physics learning through interactive and technology-supported approaches, but they differ in their primary focus. McKagan et al. (2008) examined the development and educational use of PhET simulations, providing a broader foundation for their application in Physics education. In contrast, Srisawasdi et al. (2014) focused specifically on visualization skills, while Ukozor et al. (2016) and Muhamad et al. (2020) addressed students' scientific skills, attitudes and experiences in technology-supported learning. Tan et al. (2023) focused on conceptual difficulties, particularly misconceptions about energy conservation. Taken together, these studies highlight complementary aspects of learning, including visual reasoning, conceptual understanding and students' responses to interactive learning environments.

Research Gap

Although previous studies have investigated visualization skills and the educational potential of interactive simulations in Physics, the relationship between students' self-reported visualization skills and their conception of learning through PhET simulations remains insufficiently explored in the literature reviewed for this study. In particular, these two variables represent distinct aspects of students' reported learning experiences: their perceived ability to interpret and represent visual information and their perceptions of understanding abstract concepts, cognitive engagement and learning through PhET. Therefore, this study addresses this gap by

examining both variables among 60 Form 4 Physics students from secondary school in Malaysia and investigating whether a statistically significant relationship exists between them.

METHODOLOGY

Research Design

This study employed a quantitative approach using a descriptive-correlational research design to examine Form 4 students' self-reported visualization skills and conception of learning through PhET simulations in Physics. Data were collected using a structured questionnaire comprising items on visualization skills and conception of learning. Descriptive statistics, including means and standard deviations, were used to determine the levels of both variables. Pearson's correlation coefficient was used to examine the relationship between students' self-reported visualization skills and their conception of learning through PhET simulations. This design enabled the study to describe both variables and examine the relationship between them, addressing the three research questions.

Participants and Sampling

The target population comprised Form 4 secondary school students in Johor, Malaysia, who were enrolled in Physics classes where PhET simulations were integrated into instruction. A homogeneous purposive sampling technique was employed to select students who met the study's inclusion criteria: (i) enrolment in the KSSM Form 4 Physics syllabus, (ii) prior experience learning Physics through PhET simulations for at least one major topic and (iii) access to adequate technological facilities for using the simulations. Five secondary schools were contacted, of which two agreed to participate. One school was selected for the pilot study, while the other was used for the main data collection to avoid overlap between the pilot and main-study participants. The main study involved 60 Form 4 Physics students who met the inclusion criteria and provided informed consent. Their questionnaire responses were analysed to examine their self-reported visualization skills, conception of learning through PhET simulations and the relationship between these variables.

Research Instrument

Data were collected using a structured questionnaire administered through Google Forms. The questionnaire comprised three sections: demographic information, self-reported visualization skills and conception of learning through PhET simulations. The demographic section collected information on participants' gender (male or female), class name (4A or 4B) and frequency of PhET simulation use (often or seldom). The second section consisted of 11 items assessing four constructs of visualization skills: analyzing visual information (3 items), describing Physics concepts visually (2 items), illustrating Physics scenarios (3 items) and outlining key concepts visually (3 items). These items were adapted and contextualized from the DCEC–ViSIT instrument developed by Srisawasdi et al. (2014) and visualization research by Yen et al. (2021). The third section contained 15 items measuring conception of learning through three constructs: understanding abstract concepts in Physics (5 items), cognitive engagement with PhET simulations (4 items), and personal perception of learning through PhET (6 items). Items in this section were adapted from studies by Ukozor (2016) and Muhamad et al. (2020). All 26 construct items were rated on a four-point Likert scale: 1 (strongly disagree), 2 (disagree), 3 (agree), and 4 (strongly agree). The scale omitted a neutral midpoint to encourage respondents to indicate their level of agreement.

Validity and Reliability

The questionnaire was reviewed by three experts to assess content relevance, language clarity and alignment between the items and their intended constructs. A pilot study involving 42 secondary school students with characteristics similar to those of the target population was conducted to assess the questionnaire before the main data collection. These participants were separate from the 60 students involved in the main study.

The internal consistency of the questionnaire was assessed using Cronbach's alpha. Analysis of the pilot data produced coefficients ranging from .712 to .883 across the seven constructs, with an average coefficient of .837. Specifically, the coefficients were .842 for analyzing visual information, .712 for describing Physics concepts

visually, .859 for illustrating Physics scenarios, .841 for outlining key concepts visually, .868 for understanding abstract concepts in Physics, .855 for cognitive engagement with PhET simulations, and .883 for personal perception of learning through PhET. Overall, the results indicate acceptable to good internal consistency across the constructs.

Data Collection and Ethical Considerations

Data collection and ethical consideration: Following the necessary ethical approval and school permissions, data were collected from 60 Form 4 Physics students at one secondary school in Johor, Malaysia. The questionnaire was administered through Google Forms to obtain students' responses on their self-reported visualization skills and conception of learning. The completed responses were compiled for subsequent statistical analysis.

Permission to conduct the study in the school was obtained through the Education Research Application System (ERAS). As the participants were secondary school students, informed consent was obtained from both the students and their parents or legal guardians. Participation was voluntary, and the study's objectives, procedures and confidentiality measures were communicated to the participants and their guardians. Only students who provided their own consent and whose parents or legal guardians had also provided consent were included in the study.

Data Analysis

The questionnaire data were analysed using the Statistical Package for the Social Sciences (SPSS). Frequencies and percentages were used to summarise participants' demographic characteristics, while means and standard deviations were calculated to describe their self-reported visualization skills and conception of learning. Mean scores were interpreted using a four-point scale, with higher scores indicating higher levels of agreement. Based on the interpretation criteria adopted from Upara et al. (2023), mean scores were classified as low (1.00–1.74), moderate (1.75–2.49), high (2.50–3.24) or very high (3.25–4.00).

The Shapiro–Wilk test was conducted to assess the normality of the data before correlation analysis. Pearson's correlation coefficient was used to examine the strength, direction and statistical significance of the relationship between students' self-reported visualization skills and their conception of learning. Spearman's rank-order correlation was identified as the alternative if the normality assumption was not met. Statistical significance was assessed at the .05 level.

FINDINGS

The analysis examined students' self-reported visualization skills, conception of learning through PhET simulations and the relationship between these constructs. Descriptive statistics were employed to characterize the levels of each construct, while Pearson's product–moment correlation coefficient was used to determine the strength and direction of the relationship between the two variables among 60 Form 4 Physics students.

Students' Self-Reported Visualization Skills

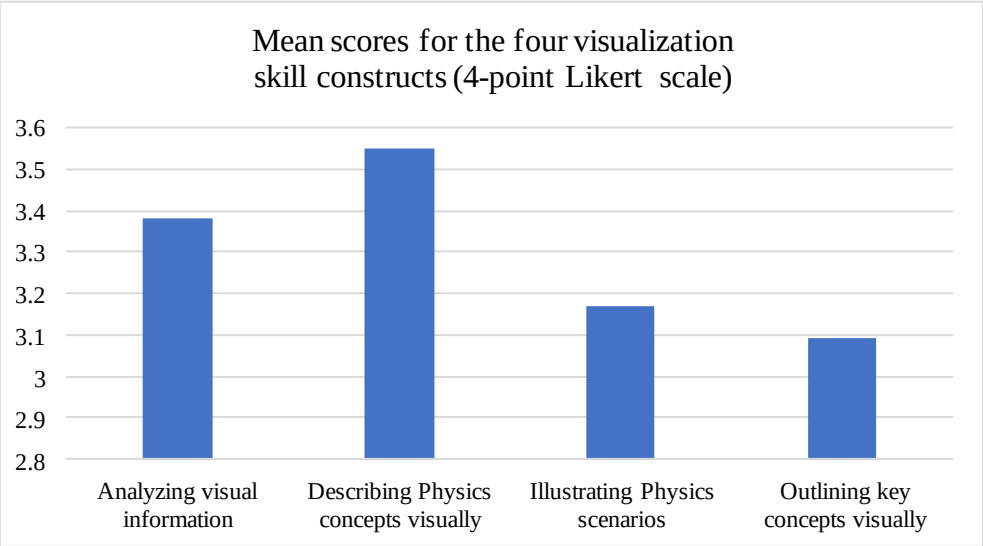
Students reported high to very high levels of self-reported visualization skills across the four constructs, with mean scores ranging from 3.09 to 3.55. The descriptive statistics for each construct are presented in Table 2.

Table 2. Descriptive Statistics for Self-Reported Visualization Skills (n = 60)

Construct	Mean	SD	Level
Analyzing Visual Information	3.38	0.449	Very high
Describing Physics Concepts Visually	3.55	0.417	Very high
Illustrating Physics Scenarios	3.17	0.462	High
Outlining Key Concepts Visually	3.09	0.501	High

As shown in Table 2, Describing Physics Concepts Visually recorded the highest mean score (M = 3.55, SD = 0.417), followed by Analyzing Visual Information (M = 3.38, SD = 0.449). Both constructs were classified as very high, while Illustrating Physics Scenarios (M = 3.17, SD = 0.462) and Outlining Key Concepts Visually (M = 3.09, SD = 0.501) were classified as high. These findings indicate that students reported particularly high levels of confidence in describing Physics concepts visually and analysing visual information. Figure 1 illustrates the mean scores across the four visualization skill constructs.

Figure 1. Mean scores of students' self-reported visualization skills when learning Physics through PhET simulations.



Students' Conception of Learning

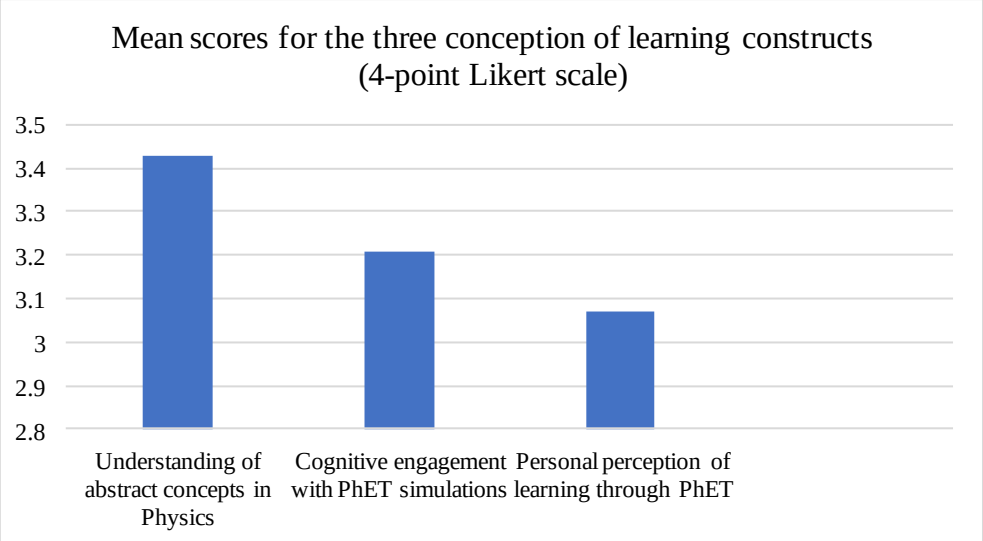
Students reported high to very high levels of conception of learning through PhET simulations across the three constructs, with mean scores ranging from 3.07 to 3.43. The descriptive statistics for each construct are presented in Table 3.

Table 3. Descriptive Statistics for Conception of Learning (n = 60)

Construct	Mean	SD	Level
Understanding of Abstract Concepts in Physics	3.43	0.387	Very high
Cognitive Engagement with PhET Simulations	3.21	0.428	High
Personal Perception of Learning Through PhET	3.07	0.461	High

As shown in Table 3, Understanding of Abstract Concepts in Physics recorded the highest mean score (M = 3.43, SD = 0.387) and was classified as very high. Cognitive Engagement with PhET Simulations (M = 3.21, SD = 0.428) and Personal Perception of Learning Through PhET (M = 3.07, SD = 0.461) were classified as high. Overall, these findings indicate that students reported favourable perceptions of their learning through PhET simulations, particularly in relation to understanding abstract Physics concepts. Figure 2 illustrates the mean scores across the three constructs of students' conception of learning through PhET simulations.

Figure 2. Mean scores of students' conception of learning through PhET simulations in Physics.



Relationship Between Visualization Skills and Conception of Learning

Pearson's correlation coefficient was used to examine the relationship between students' self-reported visualization skills and their conception of learning. The results are presented in Table 4.

Table 4. Pearson Correlation Between Visualization Skills and Conception of Learning (n = 60)

Variables	Pearson's r	p-value	Interpretation
Self-reported visualization skills and conception of learning	0.32	0.013	Weak positive, statistically significant relationship

The analysis revealed a weak positive, statistically significant relationship between students' self-reported visualization skills and their conception of learning through PhET simulations ($r = .320$, $p = .013$, $n = 60$). As the p-value was below the .05 significance level, the null hypothesis of no relationship was rejected. The positive correlation indicates that students who reported higher visualization skills also tended to report a more favourable conception of learning through PhET simulations. However, the correlational nature of the study does not establish a causal relationship between the variables.

DISCUSSION

The descriptive findings indicated high to very high levels of self-reported visualization skills and conception of learning through PhET simulations. In particular, describing Physics concepts visually and understanding abstract concepts in Physics recorded very high mean scores under the adopted interpretation criteria. These findings suggest that students generally perceived themselves as capable of interpreting visual representations and understanding abstract Physics concepts when using PhET simulations. However, the comparatively lower mean for outlining key concepts visually suggests that students may benefit from additional guidance in organizing visual information into structured representations, such as diagrams and concept maps. This observation can be considered in relation to Mental Model Theory, which highlights the role of mental representations in understanding complex phenomena (Johnson-Laird, 1983).

The findings are also consistent with previous studies that have discussed the potential of PhET simulations in supporting conceptual understanding and student engagement (Muhamad et al., 2020; McKagan et al., 2008). The use of interactive visual representations in PhET simulations may provide students with opportunities to explore Physics concepts and observe relationships between variables. Nevertheless, the present findings reflect students' self-reported perceptions rather than objectively measured learning gains. Therefore, the results should be interpreted in terms of students' perceived visualization skills and conceptions of learning ra-

ther than actual improvements in academic performance.

Despite the generally high scores reported for both variables, Pearson's correlation analysis revealed a weak positive, statistically significant relationship between students' self-reported visualization skills and their conception of learning through PhET simulations ($r = .320$, $p = .013$). This finding suggests that students who reported stronger visualization skills also tended to report more favourable conceptions of learning through PhET simulations. One possible explanation is that students who are more confident in interpreting and organizing visual representations may also perceive greater value in simulation-based learning. Visualization skills involve interpreting and organizing visual information, whereas conception of learning reflects students' views and beliefs about learning (Purdie et al., 2002). However, the relatively weak correlation indicates that other factors may also be associated with students' conceptions of learning. Nevertheless, these findings should be interpreted cautiously, as the correlational design does not establish causation and the data were based on students' self-reports.

Implications and Limitations

The findings suggest that teachers could complement PhET simulations with activities that require students to draw, interpret and explain visual representations. Teachers could also incorporate reflective questions to encourage students to consider their own learning experiences. These activities may provide additional support for students in organizing visual information and reflecting on Physics concepts.

However, this study involved only 60 students from one secondary school in Johor, which may limit the generalisability of the findings to other student populations. Furthermore, the study relied on questionnaire data based on students' self-reported perceptions rather than objective assessments of their actual visualization skills or learning outcomes. The correlational research design also does not establish a causal relationship between the two constructs or demonstrate actual improvements in learning. Future research could involve larger samples from multiple schools and incorporate objective assessments to examine these relationships further.

CONCLUSION & RECOMMENDATIONS

This study examined secondary school students' self-reported visualization skills and their conception of learning through PhET simulations in Physics. The findings indicated that students reported high to very high levels of self-reported visualization skills and conception of learning through PhET simulations. Among the four visualization skill constructs, describing Physics concepts visually recorded the highest mean score, while understanding abstract concepts in Physics recorded the highest mean score among the three conception of learning constructs. Pearson's correlation analysis revealed a weak positive, statistically significant relationship between the two variables ($r = .320$, $p = .013$). This suggests that students who reported higher visualization skills also tended to report a more favourable conception of learning through PhET simulations. However, the correlational nature of the study does not establish a causal relationship between these variables.

Based on these findings, Physics teachers could complement PhET simulations with guided activities that involve drawing diagrams, interpreting visual representations, explaining simulated phenomena and organizing key concepts. Future research should involve larger and more diverse samples from multiple schools and incorporate objective assessments of visualization skills and Physics understanding. These approaches could provide a more comprehensive understanding of the relationship between students' visualization skills, their conception of learning and their learning experiences in Physics. Additionally, future studies could examine how students' prior knowledge and familiarity with visual learning activities influence their experiences when using PhET simulations.

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