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Investigating the Efficacy of Interactive Simulations (Phet) in Improving Students' Understanding of Chemistry Concepts in a Private High School in Abu Dhabi

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Abstract

The study aims to investigate the efficacy of interactive simulations (PhET) in improving students' understanding of chemistry concepts in a private high school in Abu Dhabi. The study follows a mixed-method approach, using both qualitative and quantitative data collected from 20 Emirati senior female participants. The participants were given a questionnaire comprising 12 Likert Scale statements addressing their attitudes and knowledge, along with three open-ended questions. The questionnaire was validated by a panel of experts. The study was conducted during the academic year of 2018-2019. Descriptive statistics and thematic analysis were used to analyze the quantitative and qualitative data collected from the participants. The findings suggest that interactive simulations such as Physics Education Technology (PhET) are effective teaching and learning tools that enhance students' confidence and enrich their learning experiences in chemistry whether used synchronously or asynchronously. Future research could further explore the potential of these simulations in enhancing critical thinking and problem-solving skills, given their alignment with the PDEODE (Predict, Discuss, Explain, Observe, Discuss, and Explain) learning model.

Keywords: Interactive Simulations, Physics Education Technology (PhET), Chemistry

1. Introduction

The Chemistry is perceived as one of the most challenging subjects in high school (Dermicioglu, Ayas & Dermicioglu 2005, Oladejo, Akinola, & Nwaboku, 2021). Although chemistry application lies in everyday life (Widyastuti et al. 2019), many students have difficulties understanding chemistry concepts and reveal lots of misconceptions, especially in acids and bases, stoichiometry, and covalent bonding (cited in Dermicioglu, Ayas & Dermicioglu 2005, p.37). While various interventions have been tested around the world to enhance the performance of secondary school chemistry students, the majority of these interventions only concentrate on classroom teaching methods and overlook the learning resources that are specific to the subject itself (Oladejo 2018).

To improve students' understanding of chemistry, computer simulation is seen as a powerful educational tool that can make learning more engaging, fun, and relevant (Liu, Lin, Hsu, Hsu & Paas, 2021, Perkins et al. 2012). One such simulation tool is the Physics Education Technology (PhET), which offers interactive offline and online free simulations in physics, biology, and chemistry (Alhadlaq et al. 2012, Ganasen & Shamuganathan, 2017). These simulations have been widely used in chemistry as they allow students to access different levels of representation and visualize objects that cannot be directly observed by the eye (Watson, Dubrovskiy & Peters, 2020).

Since students' understanding is based on their interaction of what they already know and believe with phenomena or ideas (Gold-Veerkamp, Abke & Diethelm, 2017), the PhET simulation tool is chosen as it is consistent with the PDEODE learning model (Predict, Discuss, Explain, Observe, Discuss, and Explain). This model links prior knowledge to newly acquired knowledge, enhancing students' learning experience (Yunita, 2012, as cited in Widyastuti et al. 2019, p.2).

Integrating technology in classrooms has opened up new opportunities for learning and teaching. The pandemic has increased computer availability and smart boards in schools. Interactive simulations like PhET have been added to courses such as chemistry to enhance student's learning experiences and improve teaching. This intervention tackles the difficulties of teaching complex subjects and enables learners to work at a level beyond their cognitive skills. Thus, investigating the efficacy of this interactive simulation by exploring students' perceptions will highlight the importance of this intervention in UAE chemistry classrooms, and improve pedagogical delivery (Gong et al. 2015) as simulations enable the learner to work at a level that surpasses the limitations of their cognitive skills (Duffy & Jonassen 1992).

1.1 Statement of the Problem

The uses of computer technology have started ever since the knowledge revolution took place at the beginning of the 20th century. This knowledge-age technology empowered by computer simulations, video games, and artificial intelligence, enabled students of all ages and abilities to pursue learning on their terms and based on their goals and interests (Collins & Halverson 2018). Interactive science simulation, such as Physics Education Technology (PhET), is an effective educational tool commonly used in science (Moore, Smith & Ramdal 2016, Watson, Dubrovskiy & Peters, 2020) as it encompasses free simulations targeting mainly physics but has expanded to include chemistry, biology, and mathematics from middle school up to college (Perkins & Wieman 2018). The use of such tools inhibits students' competencies, skills, and knowledge development required for the twenty-first century. Nowadays, these interactive simulations are powerful tools emerging mainly to support chemistry learning (Moore et al. 2014) especially since chemistry is considered a complex subject that requires mathematical skills (Stieff & Wilensky 2011).Many research studies have shown the effectiveness of PhET interactive simulations in increasing students' engagement, motivation, and learning outcomes mainly in physics or biology (Adams 2010; Summak, Samancioglu & Baglibel 2010; Rutten, Van Joolingen & Van der Veen 2011; Kukkonen et al. 2013; Correia et al. 2019), very limited research studies used a mixed method to tackle students' perceptions towards implementing this educational tool in chemistry, particularly in the United Arab Emirates. Therefore, the current research sheds light on Emirati senior students' perceptions mainly addressing their attitudes and knowledge towards using PhET simulations in chemistry lessons especially that according to the UAE national agenda, Emirati students must become innovative and productive citizens to develop a competitive knowledge-based economy leading the growth of their nation. This can only happen through socioeconomic development led by science, innovation, and technology (UAE Ministry of Cabinet Affair 2015, p. 6).

1.2 Purpose and Research Questions of the Study

The research study aims to investigate high school students' perceptions and attitudes towards PhET simulations in understanding chemistry concepts on molecule polarity in Abu Dhabi, the capital of UAE.

To address the main purpose, the study will focus on the following research questions:

1. What are high school students' perceptions of the PhET simulation in enhancing the chemistry concept of polarity?

2. What are the attitudes of high school students towards the uses of PhET simulation in understanding molecule polarity in chemistry lessons?

2. Theoretical Framework

The study was based on two essential frameworks: interactive constructivism, and the unified theory of use and acceptance of technology (UTAUT).

2.1Constructivism

Constructivism is a learning theory that has influenced education and instructional technology fields since the 1990s (Woo & Reeves 2007). It considers the student's attitudes and experiences as critical to the learning process

(Olusegun 2015). According to Fosnot & Perry (2005), constructivism rests on the assumption of the current psychology of learning and development, rather than a description of teaching. This theory explains how learners gain insight into knowledge and learning. While knowledge is built by students as they make sense of their experiences, Bruner (in Culatta 2018) defined learning as a process that builds on individuals' current and past understandings. Influenced by Vygotsky, Bruner incorporated the social and cultural aspects of learning in his theory especially since knowledge can be generated from learner's experiences and interactions. Since the study is based on students' interaction with simulations and peers, interactive constructivism is adopted. This particular type of constructivism will lead the students to reflect, construct knowledge and understand the current unit "molecule polarity". Moreover, this type of activity learning merges radical constructivism, social constructivism, and information processing into its learning theory (Reich 2007). While radical constructivism advocated by von Glasersfeld emphasizes that knowledge and learning are self-generated through experience (in Reich 2007, p.10), Vygotsky's social constructivism states that learning is an active social discovery and construction of knowledge, that occurs through cooperative learning, and classroom discussions (in Kivunja 2014, p.83). Since the main purpose of science is equipping students with knowledge and skills that allow them to tackle real-life problems with a critical mindset, Vygotskys' zone of proximal development (ZPD) is an imperative element of the conceptual framework. This socio-cultural Vygotskian concept is defined as what students can do and achieve with or without any help or guidance. However, a relationship between Vygotskys' ZPD and scaffolding was shown especially since implicit scaffolding was a useful framework in interactive simulations particularly in mathematics and science (Podolefsky, Moore & Perkins 2013a). The PhET simulation was built on implicit scaffolding, whereby students were guided through an activity sheet to help them construct their knowledge and reach a higher level of achievement.

2.2 Unified Theory of Use and Acceptance of Technology (UTAUT)

Several theories have been developed to predict the acceptance of technology. According to Ajzen and Fishbein (1975), the theory of reasoned action (TRA) explains the relationship between behavior and attitude on one side and intention and norms on the other side. TRA suggests that acceptance or rejection of technology is linked to a person's norms, intentions, and attitudes. However, since intentions do not always predict behavior, an extension to TRA called the theory of planned behavior (TPB) (Ajzen 1980) was created. The technology acceptance model (TAM) (Davis et al. 1989) and the unified theory of acceptance and use of technology (UTAUT) were also extensions to TPB. However, research studies have found that TAM is culturally reliant and invalid in Japan, Singapore, and Malaysia (Venkatesh et al. 2003; Teo et al. 2008, as referenced in Echeng & Urso 2016). On the other hand, UTAUT was developed by combining eight models, of which TRA, TBP, and TAM were part. This theory is validated through different cultural contexts and attempts to determine the relationship between acceptance and use of technology and behavior (Echeng & Urso 2016, p. 92). In UTAUT, behavioral intention was replaced by the attitudes of students, teachers, and parents since intention only examines internal motivations to use the technology (Venkatesh, Morris, & Ackerman, 2000, as referenced in Echeng & Urso 2016). Therefore, UTAUT was chosen as one of the theoretical frameworks adopted in this study since the attitudes of students towards the use of technology, particularly PhET interactive simulation, were one of the fundamental interests in this research.

3. Literature Review

Understanding chemistry concepts needs the acquisition of knowledge based on three levels; macroscopic, symbolic, and particulate (Johnstone 1982 cited by Herrington, Sweeder & VandenPlas 2017, p. 359). For the past thirty years, researchers have been arguing about this idea in the education of chemistry (Taber 2013). Recently, the integration of computer technology that includes simulations and animations provided a visual representation of molecules at a macroscopic and microscopic level. Using these simulations and animations has helped increase students' understanding of scientific concepts, mainly chemistry and physics (Akaygun & Jones 2013). Since many students cannot visualize processes and structures at a molecular level, simulation-based learning facilitates scientific phenomena (Correia et al. 2018; Watson, Dubrovskiy & Peters, 2020) by offering an interactive for exploring these phenomena in the real-world context (Luo et al. 2016). The researcher aimed to examine the perceptions of female Emiratis towards the uses of Physics Education Technology (PhET) interactive simulation in chemistry lessons. PhET has been proven to be a powerful tool for teaching and learning science, designed with minimal text, and targets student engagement through interactive, animated, game-driven platforms (Adams 2010). Founded by Nobel Laureate Carl Wieman (PhET interactive simulations 2019) at the University of Colorado, this free interactive simulation includes over 85 simulations in physics, 30 in chemistry, and additional simulations in maths and biology. Moreover, PhET is accessible in 79 languages (Moore 2016), and since May 2017, it has been available for students with visual or mobility impairments (Moore & Perkins 2017). Thus, integrating the PhET simulations into chemistry can enhance students' understanding of concepts, addressing diverse levels, abilities, skills, and needs.

While several research studies(Adams 2010; Correia et al. 2019; Ekmekci & Gulacar 2015; Gong et al. 2015; Moore & Perkins 2017; Oladejo 2018; Rahmawati et al., 2022; Rutten, Van Joolingen & Van der Veen 2011; Summak, Samancioglu & Baglibel 2010; Watson, Dubrovskiy & Peters, 2020) indicate that interactive simulations effectively enhance students' skills, facilitate the learning process, and boost engagement and motivation. Summak, Samancioglu, and Baglibel (2010) found that integrating computer technology enriches students' understanding of subject concepts, motivates active learning, and supports knowledge transfer to real-world problem-solving. PhET simulations are particularly effective in ensuring students' achievement in science (Adams 2010) and promoting learning outcomes (Rutten, Van Joolingen & Van der Veen 2011). Correia et al. (2019) emphasized the benefit of using PhET simulation in chemistry classrooms. The study which surveyed 114 secondary students, evaluated their perceptions of how PhET simulations impact learning. Additionally, PhET's implicit scaffolding ensures that students learn without explicit guidance (Moore, Smith & Ramdal 2016). For example, Kukkonen et al. (2013) demonstrated how simulation-based inquiry learning in a grade five greenhouse effect lesson enriched students' understanding through drawings and increased their learning outcomes by leveraging scaffolding. Associating simulations with inquiry-based learning methods has been shown to enhance science learning (Rutten, Van Joolingen & Van der Veen 2011; Podolefsky, Moore & Perkins 2013b). Interactive simulations also complement hands-on learning activities. Ekmekci and Gulacar (2015) compared technology-based simulations to traditional hands-on instructional designs, finding similar learning gains in both approaches for understanding scientific concepts mainly in physics through pre-post tests analysis. Gong et al. (2015) highlighted simulations' effectiveness in visualizing complex phenomena, such as quantum mechanics, though some students noted limitations in providing physical explanations. Perkins et al. (2012) found that PhET simulations significantly increased engagement in middle school science classrooms from grade 5 to grade 8.

Combining interactive simulations with structured instructional models, such as the 5E inquiry learning model (Engaging, Exploring, Explaining, Extending, and Evaluating), yields promising results. Sari et al. (2017) studied 80 grade 11 students and found that the experimental group using the 5E model with interactive simulations demonstrated better conceptual understanding and positive attitudes toward physics than students taught using traditional methods.

Emerging research highlights the potential of integrating PhET simulations with collaborative and peer-assisted learning to enhance critical thinking and problem-solving skills. Rahmawati et al. (2022) found that such strategies improved conceptual understanding and student confidence in tackling chemistry problems. Olugbade et al. (2024) found that using PhET interactive simulations significantly improved junior secondary students' academic performance, motivation, and attitudes toward Basic Science and Technology in Nigeria just emphasizing further the importance of interactive simulations in accommodating diverse learning styles, enabling personalized pacing, and fostering inquiry.

Despite these findings, research on PhET's use in chemistry education, particularly in the UAE, remains limited. This study focuses on grade 12 Emirati students' attitudes and knowledge gains when using PhET simulations guided by activity worksheets and peer collaboration. The mixed-method research will adopt a phenomenological case study design, collecting data through surveys to explore the effectiveness of this innovative instructional approach.

4. Methodology

4.1 Research Design

The study followed a mixed-method research approach to answer its research questions. The research design was an explanatory sequential design, incorporating a phenomenological approach to explore students' perceptions of using PhET interactive simulations in a chemistry molecule polarity lesson (Creswell & Guetterman, 2019). Additionally, a case study approach was adopted to address "why" and "how" questions within a real-life context (Yin, 2002). This design aimed to gain both qualitative and quantitative insights into the efficacy of PhET simulations in improving students' understanding of chemistry concepts.

4.2 Sample and Data Collection

Purposive sampling was employed, focusing on the Grade 12 chemistry class at a private high school in Abu Dhabi. The sample consisted of 20 female Emirati students aged 15–19, enrolled in chemistry as part of their credit requirements for university pathways, particularly in medicine and engineering. The small class size reflected the school's American Program, which allows students to select courses throughout the academic year. The study targeted molecule polarity as part of the Grade 12 curriculum, with specific learning goals (Table 1). Students worked in pairs to explore the PhET simulation, engaging in hands-on activities using an activity sheet divided into three sections (Appendix 1). They manipulated variables, recorded observations, and discussed their findings within their pairs. In the final section, students predicted and explained the polarity of three molecules and created graphic organizers to summarize the factors influencing molecule polarity. This process was facilitated by a student-centered teaching approach, encouraging active learning and collaboration.

Table 1. Molecule polarity Learning Outcomes

Students will be able to:
1. Determine the relationship between electro-negativity and bond character
2. Explain the relationship between electro-negativity and electron density.
3. Explain how electro-negativity and molecule geometry determine molecule polarity.
4. Explain the relationship between bond dipole and molecular dipole

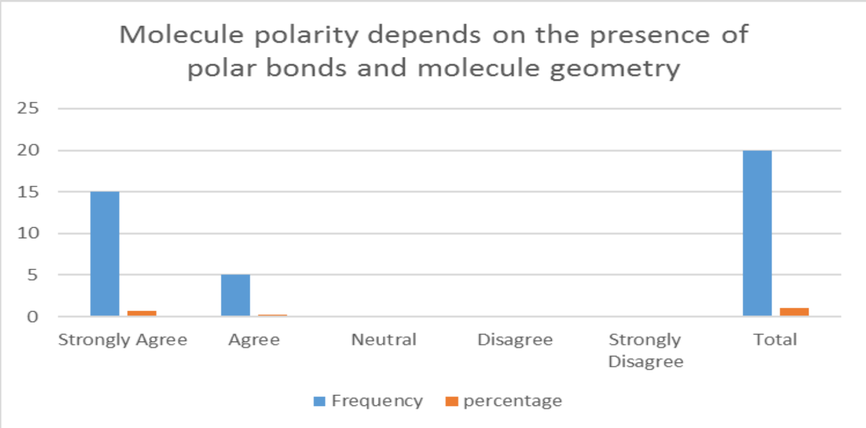
4.3 Analyzing Data

Data on students' knowledge and attitudes toward the use of PhET simulations were collected via a validated questionnaire (Appendix 2). Content validation was conducted by educational experts and chemistry teachers, with additional feedback from two Grade 12 students to ensure clarity. The questionnaire comprised three sections: demographic questions, Likert-scale statements assessing knowledge and attitudes, and open-ended questions for capturing nuanced insights. The Likert-scale responses ranged from Strongly Agree (5) to Strongly Disagree (1). The open-ended section, informed by Dobbins and Denton (2017), provided an opportunity for students to elaborate on their experiences. The survey was administered anonymously at the end of the final chemistry lesson to ensure ethical adherence and voluntary participation.

5. Data Analysis

The quantitative analysis was carried out by using the questionnaire based on Likert Scale responses. Descriptive statistical analysis was carried out to obtain the outcomes. The Skewness and kurtosis were calculated to evaluate the presence or lack of symmetry, while Kurtosis measured the readings were light-tailed or high with respect to normal distribution. The first statement, which was asked of the participant was, "Molecule polarity depends on the presence of polar bonds and molecule geometry". In response, most of the participants strongly agreed (75%) or agreed (25%) with the statement (Figure 1) highlighting their agreement on the above concept.

Figure 1. Graph showing the variation of responses on molecule polarity dependence in terms of frequency and percentages.



In addition, the outcomes of descriptive statistics provided a mean value of 4.75 and a standard deviation of 0.099. Furthermore, the Kurtosis and Skewness values indicated that most of the findings are negatively skewed which indicates that prime outcomes are toward strongly agreed option (Table 2).

Table 2. Statement 1 Descriptive Statistics.

N	**Mean**	**Standard Error**	**Median**	**Mode**	**Standard Deviation**	**Sample Variance**	**Kurtosis □□□□□ □□2)**	**Skewness □□□□□□□ □□□1)**
20	4.75	0.09934	5	5	0.444262	0.197368	-0.49673	-1.25051

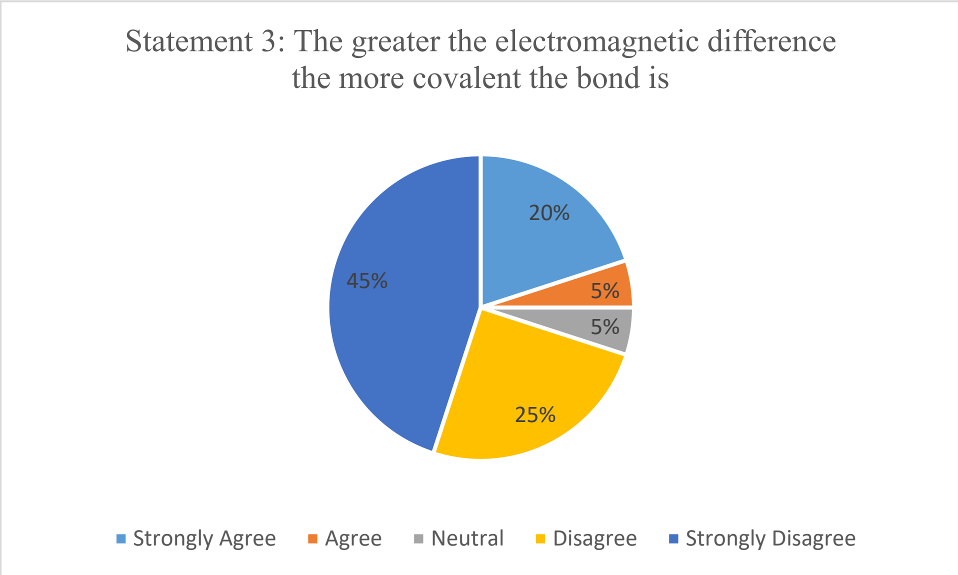
Regarding the second statement, "Dipoles are represented by arrows pointing towards the more electronegative atom", participants either strongly agreed (75%) or agreed (25%) with the statement None of the participants disagreed with this statement. In addition, the outcomes of descriptive statistics provided a mean value of 4.75 and a standard deviation of 0.099. Furthermore, the Kurtosis and Skewness values indicated that most of the findings are negatively skewed and this indicated that prime outcomes are towards strongly agreed option as observed in Table 3.

Table 3. Statement 2 Descriptive Statistics.

N	**Mean**	**Standard Error**	**Median**	**Mode**	**Standard Deviation**	**Sample Variance**	**Kurtosis □□□□□ □□2)**	**Skewness □□□□□ □□□□1)**
20	4.75	0.099339	5	5	0.444261	0.197368	-0.49673	-1.25051

In response to the third statement, "The greater the electromagnetic difference the more covalent the bond is", the participants provided a mixed response. 20% of the participants strongly agreed, while 45% strongly disagreed and 25% disagreed with the statement. Based on the outcomes, it is clear that most of the participants disagreed that the greater the electromagnetic difference the more covalent the bond is. The graphical presentation is presented below (Figure 2).

Figure 2. Graph showing the variation of responses on the representation of dipole.



In addition, the outcomes of descriptive statistics provided a mean value of 2.3 and a standard deviation of 0.35, which indicates most of the responses are toward disagreeing and the standard deviation value shows high variance. Furthermore, the Skewness value (0.927440884) indicated that most of the findings are positively skewed and this indicated that prime outcomes are negatively i.e. strongly disagreed option.

In response to the fourth statement, “A molecule electrostatic potential is white whenever the molecule is polar”, 20% of students strongly agreed and 10% agreed; however, 70% of participants strongly disagreed with the statement. This revealed that the students do not agree that a molecule's electrostatic potential is white whenever the molecule is polar. The outcomes of descriptive statistics provided a mean value of 1.55 and a standard deviation of 0.22, which indicates most of the responses are toward strongly disagree and the standard deviation value shows low deviation from the mean value. Furthermore, the Kurtosis and Skewness value

(γ_1 =1.785112, γ2=2.116854) indicated that most of the findings are positively skewed and this indicated that prime outcomes are negative i.e. strongly disagreed option.

In response to the fifth Statement, “PhET simulation has helped me understand fundamental molecular polarity concepts”, 60% of the participants strongly agreed while, 30% agreed with the statement, while 5% disagreed and 5% strongly disagreed with the statement. In addition, the outcomes of descriptive statistics provided a mean value of 4.05 and a standard deviation of 0.22. Furthermore, the Skewness value (γ_1 = -1.869656066) indicated that most of the findings are negatively skewed and this indicated that prime outcomes are towards strongly agreed option. In response to, “PhET simulation has helped me tackle all the variables that influenced the polarity of a molecule”, 50% of participants strongly agreed and 50% participants agreed with the statement. This revealed that most of the participants considered PhET simulation as effective to tackle different variable influencing molecular polarity. The outcomes of descriptive statistics provided the mean value of 4.5 and standard deviation of 0.11. Furthermore, the kurtosis value was negative, while Skewness value is zero, which indicated that most of the findings are negatively skewed and this indicated that prime outcomes are towards strongly agreed option. In response to “PhET simulation has increased my interest in chemistry”, 55% of participants agreed, while 40% of participants strongly agreed with the statements. The outcomes mentioned that most participants considered PhET simulation as a means to increase their level of interest. The outcomes of descriptive statistics provided a mean value of 4.35 and a standard deviation of 0.131.

Furthermore, the kurtosis and Skewness values were negative (γ_1 = -0.212353626,

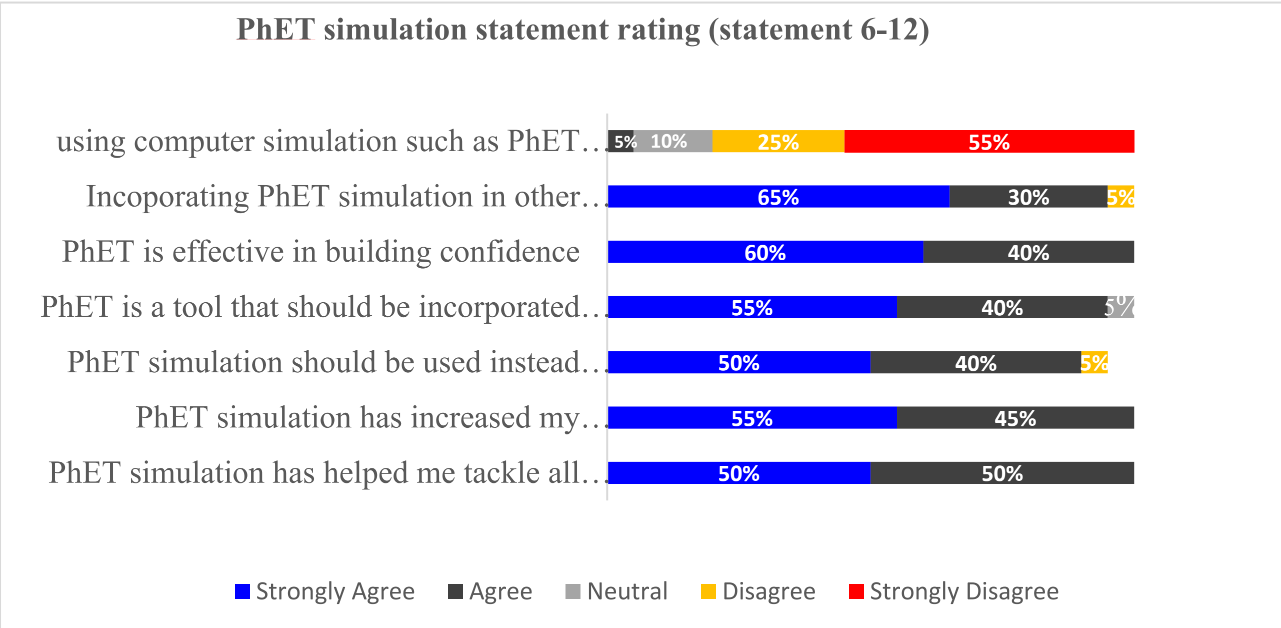
γ_2 = -0.55184407), which indicated that most of the findings are negatively skewed and this indicated that prime outcomes are towards the agreed option. In response to statement number eight, “PhET simulation should be used instead of a traditional pencil-paper activity”, 50% of participants strongly agreed and 40% agreed with the statement, and 5% disagreed. The findings of descriptive statistics provided a mean value of 4.25 and a standard deviation of 0.2161. Moreover, the Skewness value was negative (γ_1 = -1.33577), which indicated that most of the findings are negatively skewed and this indicated that prime outcomes are towards the agreed option. In response to, **“**PhET is a tool that should be incorporated in all chemistry lessons since it emphasizes collaboration among peers", 55% of participants strongly agreed, while 40% agreed with the statement. In addition, mean, standard deviation and Skewness values also indicated that most of the participants agreed with this statement (Table 4).

Table 4. Statement 9 Descriptive Statistics.

N	**Mean**	**Standard Error**	**Median**	**Mode**	**Standard Deviation**	**Sample Variance**	**Kurtosis □□□□□ 2)**	**Skewness □□□□□ □□1)**
20	4.45	0.169752	5	5	0.759155	0.576316	4.587477	-1.81849

In response to statement 10, 60% strongly agreed and 40% agreed with the statement. The mean (M), standard deviation (SD), and skewness values (M= 4.60, SD= 0.502625, γ_1 = -0.44212) also indicated that participants agreed that PhET is effective in building confidence in the study. Regarding statement 11, 65% of participants strongly agreed and 30% agreed, while only 5% strongly disagreed. The mean value was 4.55, while Skewness was -2.19141, which indicated that most of the responses were positive and that most students would like that such simulation to be incorporated into other subjects. Finally, for statement 12, 25% disagreed while 55% strongly disagreed with the statement. The mean value of 1.8 with a Skewness of 0.921888 indicated that most of the participants disagreed that using computer simulation such as PhET is stressful.

Figure 3. Graph showing the summary of students' responses on the statement 6-12.



After conducting a statistical analysis of the first part of the questionnaire using the Likert Scale, the qualitative data obtained from the three open-ended questions were compiled and analyzed. Below are the participants' responses to each of the questions asked:

1. **How effective do you think computer simulation, such as PhET, is in terms of teaching tools for learning in chemistry?**

In response to this question, one participant remarked, "I find it highly effective due to its ease of manipulation and instantaneous results. Moreover, its integration with activity worksheets enhances its utility" (Participant 5). Conversely, another participant expressed a preference for traditional teaching methods, stating, "While effective, I personally favor conventional instruction over reliance on computers" (Participant 9). Similarly, another participant highlighted the benefits of visual learning facilitated by computer simulations, noting, "The visual representation provided by this tool aids in comprehending the subject matter and understanding the correlations between variable adjustments and outcomes" (Participant 11).

Additionally, a participant emphasized the student-centered nature of the tool, remarking, "This tool fosters self-reliance, encouraging active engagement through peer and teacher interactions, thereby enhancing its effectiveness" (Participant 15). Furthermore, another participant lauded the tool's efficacy in promoting collaborative learning, stating, "PhET effectively facilitates information acquisition and validation through peer discussions, instilling confidence in the learning process" (Participant 17).

Overall, the majority of respondents attested to the tool's effectiveness, even among those with a preference for traditional teaching methods. They noted its ability to elucidate complex topics, such as molecule visualization and 3D modeling, making them more accessible to learners. Nevertheless, some participants indicated a lingering preference for traditional instructional approaches despite recognizing the merits of the tool.

2. **How would you rate your understanding of molecule polarity concepts through PhET simulation?**

Regarding responses to the second open-ended question, participants shared their insights on the impact of utilizing PhET simulations in their learning experiences. Participant 18 remarked, "The use of PhET has transformed my approach to learning. I have developed a keen understanding of molecular polarity, discerning when a molecule exhibits polarity and comprehending the influence of atom electronegativity on molecular polarity."

Additionally, participants 2 and 4 provided a comprehensive assessment of their understanding of molecular polarity concepts facilitated by PhET simulations. They stated, "We were able to elucidate key terminologies, grasp the various factors influencing molecular polarity, and correlate these principles with real-world examples, particularly understanding the unique properties of water."

Participant 7 articulated a positive perspective on the clarity of information garnered through PhET simulations, noting, "The insights gained were invaluable, particularly in comprehending the impact of molecular geometry on polarity and the correlation between electronegativity and bond type."

Furthermore, Participant 10 expressed appreciation for the structured learning approach facilitated by the accompanying worksheet, stating, "The provision of a worksheet alongside PhET usage, with real-world examples, greatly enhanced my learning experience."

Similarly, Participant 11 echoed similar sentiments, stating, "My understanding of molecular polarity and its real-world applications significantly improved through PhET simulations, particularly in understanding phenomena such as water's unique properties."

Overall, the majority of respondents acknowledged the comprehensive coverage of molecular polarity concepts provided by PhET simulations, which contributed to their enhanced understanding of the subject matter. They highlighted various topics, including factors influencing molecular polarity, polar and non-polar covalent bonds, molecular geometry, bond angles, electronegativity, and the role of dipoles. Additionally, the structured guidance offered by the accompanying worksheet was well-received. While respondents generally found the learning experience beneficial, some noted challenges in the time required to fully grasp the concepts.

3. **What did you like best about this PhET simulation learning experience?**

Responses to the final question exhibited a nuanced array of perspectives, reflecting both appreciation for real-world relevance and the empowerment of self-directed learning. Many participants commended the incorporation of real-world scenarios, recognizing its role in sustaining motivation and fostering continuous engagement with the educational system.

Participant 12 highlighted the sense of autonomy fostered by the system, stating, "I found myself able to rely on my own initiative and only sought clarification from the teacher when necessary."

Similarly, Participant 15 emphasized the development of self-reliance, noting, "We are encouraged to take ownership of our learning journey, with the flexibility to catch up at our own pace without undue pressure."

Participant 17 echoed this sentiment, expressing satisfaction with self-directed learning while appreciating the teacher's availability for queries.

Moreover, Participant 19 praised the interactive nature of the simulation, stating, "I enjoyed the hands-on manipulation of variables, exploring atomic structures, and visualizing models."

Participants attributed their engagement primarily to the user-friendly interface and manipulative capabilities of the PhET simulation, which facilitated enjoyable experimentation and exploration. The consensus among respondents underscored the enjoyment derived from using the tool, contributing to its widespread appreciation among participants. Overall, the interactive, enjoyable, and engaging nature of the PhET solution emerged as a key factor driving its adoption, indicating its indispensability in facilitating effective learning experiences.

6. Discussion

The outcomes of both qualitative and quantitative and qualitative findings revealed that computer simulation, such as PhET, is an effective teaching tool for learning chemistry. This can enhance the learning experiences of students and build the confidence level of students. The outcomes are also supported by previously conducted research studies. Ganasen and Shamuganathan (2017) demonstrated that PhET is effective in improving the skills of the students to solve chemical equations and make simulation less stressful for them. Similar to this, Putranta and Kuswanto (2018) indicated that PhET is effective in enabling the students to overcome any problem that they encountered during its use, and also lauded the availability of tutorials, thus improving their performance. The manipulation and the fact that it may be used in conjunction with the activity worksheet also seemed to satisfy its users. In addition to this, Moore and Perkins (2018) mentioned that this tool is not only effective for chemistry and its utilization extends to a wide array of subjects and is generally student-centered. The researchers indicated that using PhET is also effective for students with learning disabilities or vision or mobility impairments, as it provides an interactive learning experience to these students.

The findings of this study are also justified by Mahalingam and Fasella (2017)as this study revealed that this interactive technology improves the ability of the students to solve different chemistry-related issues. PhET and other simulation tools are effective in enhancing the learning of students. As revealed by this study, PhET simulation enhanced the skillset of students, along with triggering self-knowledge and critical thinking. Correia et al. (2019) also justify the outcomes obtained from the present research. This study mentioned that implementing PhET simulation is effective in improving the perceptions of the students in teaching different chemistry topics. This research revealed that PHET simulation is appropriate for teaching students about the behavior of gases. Similarly, Sari et al. (2019) and Rahmawati et al. (2022) also indicate that PhET is effective in improving the learning of students about chemistry. The simulation by using PhET can support the students in learning about the concepts of chemistry. The outcomes of this study indicated that PhET is effective for supporting students to learn solubility equilibrium and chemical equilibrium. Additionally, Moore (2016) indicated that the students can develop learning about different types of molecules, polarity, and how types of molecules (non-polar, polar, covalent, or ionic) influence the polarity along with electro-negativity and angle (geometry). Dutta, Atteya, and Poteat (2019)indicated that PhET simulation provides an understanding of the fundamental molecular polarity concepts and different factors and their influence on the polarity of a molecule.

PhET has shown its effectiveness in improving the interest of students to learn chemistry and ensures building their confidence in studying chemistry. Moreover, building students' knowledge through active learning tools guided by an activity worksheet, helped students reach the ZPD and impacted positively their attitude toward the use of technology in chemistry. Therefore, both the qualitative and quantitative outcomes are in line with the outcomes obtained from the previous research studies. However, this research study is subject to some limitations due to the limited number of participants from a particular high school. Therefore, to ensure the transferability of the findings a longitudinal study will be required among different private and public high school chemistry classrooms. In addition, PhET interactive simulations were implemented in senior classes for only one week since the second academic term for senior students is considered relatively short since they have governmental exams. Therefore, to track the effect of such simulations on students' knowledge it would be advisable to extend the length of the study over at least an academic term.

Finally, it would be worth studying if there is a statistically significant difference between male and female Emirati senior student perceptions after using PhET simulations in high school chemistry subjects along with examining whether implementing interactive simulations in high school scientific classes can enhance students' critical thinking and problem-solving skills.

7. Conclusion

This study explored the effectiveness of interactive simulations (PhET) in enhancing the understanding of chemistry concepts among Emirati female high school students in Abu Dhabi. The results underscore the potential of PhET simulations as an innovative and effective educational tool that fosters both confidence and deeper conceptual comprehension. By engaging students through dynamic, interactive learning experiences, PhET simulations address common misconceptions and make abstract concepts more tangible and accessible.

The integration of PhET into the chemistry curriculum proved beneficial whether applied in synchronous classroom settings or asynchronous self-paced learning, demonstrating its versatility and adaptability to different teaching approaches. The findings align with previous research emphasizing the value of digital tools in making chemistry more engaging and relevant to learners. The implications of these results extend beyond the chemistry classroom, suggesting that similar interactive tools could be adapted to enhance other STEM disciplines, such as physics and biology, which often present students with complex concepts and abstract ideas. In addition, PhET's effectiveness may extend to subjects like mathematics, where interactive visualizations can support understanding of abstract mathematical concepts.

Furthermore, this research emphasizes the potential benefits of incorporating technology into both secondary and higher education sectors. Early exposure to interactive simulations in primary education could help establish a foundation for scientific thinking and problem-solving. In higher education, particularly in STEM degree programs, these simulations could be employed to support more complex learning experiences and laboratory activities. The broader integration of digital learning tools like PhET could foster cross-disciplinary collaboration and contribute to developing a more technologically literate workforce, especially in regions focused on innovation and educational modernization.

Future studies could build on this research by examining the long-term impacts of PhET simulations on students' academic performance, as well as their ability to develop critical thinking and problem-solving skills. Additionally, exploring the efficacy of these simulations across diverse cultural and educational contexts could provide deeper insights into their broader applicability. Overall, this study highlights the importance of leveraging technology to create meaningful learning experiences and improve outcomes in challenging subjects like chemistry, with potential benefits across multiple education levels and disciplines.

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Appendices

Appendix 1: Activity sheet on Molecule Polarity

Learning goals:

1. Determine the relationship between electro-negativity and bond character
2. Explain the relationship between electro-negativity and electron density.
3. Explain how electro-negativity and molecule geometry determine molecule polarity.
4. Explain the relationship between bond dipole and molecular dipole
5. Predict and explain molecular dipole of real molecules.

Part I: Two Atoms Tab

1. Explain how the below parameters helped in understanding molecule polarity.
a. Partial charges
b. Electron density
c. Electrostatic potential
d. Electro- negativity

Part II: Three Atoms Tab

1. Explain the ways that leads to a change in polarity of the molecule?
2. How does the bond angle formed between the atoms affect the molecule polarity?
3. Does a non-polar molecule contain polar bonds? Explain your answer by referring to an example.

Part III: Real Molecule Tab

Build three molecules in the real molecular tab of the simulation. Predict and explain their polarity before checking your predictions with the simulation.

Molecule chosen (Draw molecule, show dipole and molecular dipole)	Prediction reasoning	Check prediction

Appendix 2: Questionnaire

Dear Students,

I would like to invite you to participate anonymously in this survey as part of my PhD research paper assignment in Science Education.

The aim of this survey is to investigate high school students' knowledge and attitudes towards PhET simulations in understanding chemistry concepts on molecule polarity, in Abu Dhabi.

Your responses are voluntary and will not be identified by individual. All responses will be collected, compiled and computed together and analyzed as a whole group.

Date (Day/Month/year):---------/---------/----------

Indicate your response by ticking the appropriate answer

1. Gender
   - o Female
   - o Male

2. Age
   - o 13-15
   - o 15-17
   - o 17-19

3. How long have you been taking chemistry?
   - o First year
   - o Second year
   - o Third year

4. To what extend do you agree to the following statements? Check the answer that best describes your understanding.

Statements	**Strongly Agree 5**	**Agree 4**	**Neither agree or disagree 3**	**Disagree 2**	**Strongly Disagree 1**
1. Molecule polarity depends on the presence of polar bonds and molecule geometry					
2. Dipoles are represented by arrows pointing towards the more electronegative atom.					
3. The greater the electronegative difference the more covalent the bond is.					
4. A molecule electrostatic potential is white whenever the molecule is polar.					
5. PhET simulation has helped me understand fundamental molecular polarity concepts.					
6. PhET simulation has helped me tackle all variables that influenced the polarity of a molecule					

Statements	**Strongly Agree 5**	**Agree 4**	**Neither agree or disagree 3**	**Disagree 2**	**Strongly Disagree 1**
7. PhET simulation has increased my interest towards chemistry.					
8. PhET simulation should be used instead of traditional pencil-paper activity.					
9. PhET is a tool that should be incorporated in all chemistry lessons since it emphasis collaboration among peers.					
10. PhET simulation was very effective in building my confidence in studying molecule polarity.					
11. I would like to try PhET simulation in other subject.					
12. I find that using computer simulation such as PhET is stressful.					

5. How effective do you think computer simulation, such as PhET, is in terms of teaching tool for learning in chemistry?
6. How would you rate your understanding of molecule polarity concepts through PhET simulation?
7. What did you like best about this PhET simulation learning experience?

Thank you for your cooperation