The Impact of Using the PhET Simulation on Tenth Graders' Conceptual Understanding and Attitudes Toward Chemical Reactions

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Abstract

Teaching through conventional methods is challenging for abstract concepts. The emergence of simulations gave rise to effective teaching and engaging learning opportunities for the students, as many studies have demonstrated. One such simulation is PhET which aims to illuminate challenging concepts through interaction so that learners can experience them and understand them better. This study seeks to assess the effectiveness of the "Reactants, Products and Leftovers" PhET Simulation on improving tenth graders' understanding of concepts and attitudes during the lesson on chemical reactions in comparison with traditional teaching methods. A mixed-methods approach was implemented on a sample of 10 tenth grade students. This involved two post-tests to measure the understanding of concepts, a questionnaire aimed at gauging student attitudes, as well as semi-structured interviews to examine student sentiments regarding the simulation. In addition, there was an observation grid to capture student interactions with the simulation during learned classroom activities and lessons. Overall results from the post-tests showed that using the "Reactants, Products and Leftovers" PhET simulation in teaching did not significantly enhance tenth graders' conceptual understanding as compared to traditional instruction focused on teaching chemical reactions. However, the results from the survey, interviews, and observation checklist showed that students preferred learning about chemical reactions through a simulation rather than a traditional approach. In light of these findings, it is suggested that the simulation be incorporated more extensively across longer teaching periods so educators can better evaluate its sustained impact on students' learning, conceptual development, and understanding of chemistry over time.

Keywords

PhET simulation, conceptual understanding, abstract concepts, attitudes.

مُسْتَخْلَص

تُعَدُّ المَفاهيمُ المُجرَّدَةُ مِن أَكثَرِ التَّحدّياتِ الَّتي يُواجِهُها اَلْمُتَعَلِّمينَ عِندَ تَعلُّمِهم مِن خِلالِ الأساليبِ التَّقليديَّةِ. وَلَكِن، مَعَ ظُهورِ المُحاكاةِ في تَعليمِ العُلومِ، أَصبَحَ التَّعلُّمُ أَكثَرَ فاعِليَّةً وَإِثارَةً لِاهتِمامِ اَلْمُتَعَلِّمينَ، كَما أَكَّدَت ذَلِكَ عِدَّةُ أَبحاثٍ عِلميَّةٍ. وَمِنْ بَيَنِ هَذِهِ اَلْمُحَاكَاةِ تَبْرُزُ مُحَاكَاةِ PhET الَّتي صُمِّمَت لِتُساعِدَ اَلْمُتَعَلِّمينَ عَلى تَصوُّرِ المَفاهِيمِ الصَّعبَةِ بِطَريقَةٍ تَفاعُلِيَّةٍ تُسَهِّلُ فَهمَها بِشَكْلٍ أَفْضَلٍ. تَسْعى هَذِهِ الدِّرَاسَةِ إِلَى دِرَاسَةِ أَثَرِ اِسْتِخْدَامِ " اَلْمُتَفَاعِلاتِ وَالنَّوَاتِجِ وَالْمُخَلَّفَاتِ " فِي مُحَاكَاةِ PhET فِي تَحْسِينِ اَلْفَهْمِ اَلْمَفَاهِيمِيّ وَاَلْموقِفِ لَدَى مُتَعلّميّ الصَّفّ العاشر أثناء تَعَلُّمِ اَلتَّفَاعُلاتِ اَلْكِيمْيَائِيَّةِ، مُقَارَنَةً بِالطَّرِيقَةِ اَلتَّقْلِيدِيَّةِ فِي اَلتَّدْرِيسِ. تَمَّ تَطْبِيقِ نَهْجٍ مُتَعَدِدِ اَلْأَسَالِيبِ عَلَى عَينَةٍ مُكَونَةٍ مِنْ عَشَرَةِ مُتَعلّمينَ فِي اَلصَّفِّ اَلْعَاشِرِ. وَشَمَلَ هَذَا اَلْنَهْجُ اِخْتِبَارَيْنِ بُعْدِييْنِ لِتَقْيِيمِ اَلتَّغيُّرَاتِ فِي اَلْفَهْمِ اَلْمَفَاهِيمِيِّ قَبْلَ وَبَعْدَ اِسْتِخْدَامِ " اَلْمُتَفَاعِلاتِ وَالنَّوَاتِجِ وَالْمُخَلَّفَاتِ " فِي مُحَاكَاةِ PhET،

اسْتِبْيَانًا إِلِكْتِرُونِيًّا يَهْدُفُ إِلَى تَقْيِيمِ مَوَاقِفَ المُتَعَلّمينَ تِجَاهَ اَلْتَفَاعُلَاتِ اَلْكِيمْيَائِيةِ بَعْدَ اِسْتِخْدَامِهِم لِلْمُحَاكَاةِ، وَمُقَابَلَةً شِبْهِ مُنَظَّمَةٍ لِجَمْعِ آرَاءِ الْمُتَعَلّمينَ حَولَ اَلْمُحَاكَاةِ اَلمسْتَخْدَمَةِ بِشَكْلٍ مُعمّقٍ . بِالإَضَافَةِ إِلَى ذَلِكَ، وُضِعَتْ شَبَكَةَ مُلَاحَظَةٍ لِرَصْدِ تَفَاعُلِ المُتَعَلّمينَ مَعِ اَلْمُحَاكَاةِ خِلَالَ اَلْأَنْشِطَةِ اَلْصَفِيَّةِ وَاَلْدُرُوسِ اَلْمُسْتَخْدَمَةِ. أَظْهَرَتِ اَلْنَتَائِجُ اَلْإِجْمَالِيةُ للاختبارَاتِ أَنَّ اسْتِخْدَامَ مُحَاكَاةِ " اَلْمُتَفَاعِلَات وَالنَّوَاتِجِ وَالْمُخَلَّفَاتِ " مِنَ موقَع PhET عَلَى عَدَمِ ظُهُورِ أَيّ تَحْسُنٍ فِي اَلْفَهْمِ اَلْمَفاهِيمِيّ لِمُتَعَلّميّ اَلصَّفِّ اَلْعَاشِرِ مُقَارَنَةً بِالطَّرِيقَةِ اَلتَّقْلِيدِيَّةِ فِي اَلتَّدْرِيسِ أَثْنَاءَ تَعَلُّمِ اَلتَّفَاعُلَاتِ اَلْكِيمْيَائِيَّةِ. وَمَعَ ذَلِكَ، أَظْهَرَتْ نَتَائِجَ اَلِاسْتِبْيَانِ وَالْمُقَابَلَةِ وَشَبَكَةِ اَلْمُلَاحَظَةِ أنَّ اَلْمُتَعَلِمِينَ فَضَّلُوا تَعَلُّمَ اَلْتَفَاعُلَاتِ اَلْكِيمْيَائِيَةِ مِنْ خِلَالِ اَلْمُحَاكَاةِ عَلَى اَلْنَّهجِ اَلتَّقْلِيدِيّ. فِي ضَوْءِ هَذِهِ اَلْنَتَائِجِ، يُقْتَرَحُ دَمْجُ اَلْمُحَاكَاةِ عَلَى نِطَاقٍ أَوسَعَ عَبْرَ فَتَرَاتِ تَدْرِيسٍ أَطْوَلَ، لِيَتَمَكَّنَ اَلْمُعَلّمُونَ مِنْ تَقْيِيمِ تَأْثِيرِهَا اَلْمُسْتَدَامِ عَلَى تَعَلُّمِ اَلْمُتَعَلِمِينَ، تَطَورِ مَفَاهِيمِهِم، وَفَهْمِهِم لِلْكِيمْيَاءِ مَعْ مُرُورِ اَلْوَقْتِ.

كَلِماتُ مُفْتاحِيَّةُ

مُحاكاةُ PhET، الفَهْمُ المَفاهيمي، المَفهيمُ المُجَرَّدَةُ، المَواقِفُ.

Résumé

L’enseignement des concepts abstraits à l’aide de méthodes traditionnelles reste difficile pour de nombreux élèves. Toutefois, l’introduction des simulations interactives, comme celles proposées par PhET, a contribué à rendre l’apprentissage des sciences plus efficace et engageant. PhET, notamment la simulation « Réactifs, Produits et Restes », vise à faciliter la compréhension des concepts complexes en permettant aux apprenants d’interagir directement avec les contenus. Cette présente étude a examiné l’impact de cette simulation sur la compréhension conceptuelle et l’attitude des élèves de dixième année lors de l’apprentissage des réactions chimiques, comparée à l’enseignement traditionnel. Un échantillon de dix élèves de dixième a été soumis à une méthodologie mixte comprenant deux tests post-intervention pour évaluer la compréhension, un questionnaire mesurant les attitudes, des entretiens semi-structurés pour explorer les opinions des élèves, et une grille d’observation pour analyser leur interaction active avec la simulation. Les résultats des tests n’ont montré aucune amélioration significative de la compréhension conceptuelle avec l’usage de la simulation, en comparaison avec l’enseignement traditionnel. Toutefois, les données issues du questionnaire, des entretiens et de la grille d’observation ont mis en évidence une attitude beaucoup plus positive des élèves envers l’apprentissage des réactions chimiques à travers la simulation. En conclusion, même si la simulation n’a pas entraîné de progrès notables en compréhension à court terme, elle a suscité davantage d’intérêt et de motivation chez les élèves. Il est donc recommandé d’utiliser cette simulation sur des périodes d’enseignement plus longues afin d’en évaluer l’impact durable sur l’apprentissage et la compréhension en chimie.

Mots-clés

Simulation PhET, compréhension conceptuelle, concepts abstraits, attitude.

At the middle and high school levels, chemistry is a core science subject that includes abstract concepts, especially chemical reactions, which require understanding at macroscopic, submicroscopic, and symbolic levels (Sa'diyah & Lutfi, 2023; Meliniasari & Setyarini, 2024; Correia et al., 2018). Many students struggle with chemical reactions because they cannot visualize molecular interactions or connect symbols to real phenomena (Hinton & Nakhleh, 1999; Salame & Makki, 2021). For instance, 97% of students at MA Al-Hikmah School reported difficulty with atoms, ions, and reaction equations (Meliniasari & Setyarini, 2024). Prior to understanding additional chemistry classes like chemical calculations, acids and bases, equilibrium, reaction rates, and many more, it is essential to grasp the fundamental idea of chemical processes (Seliwati, 2023). Traditional teaching methods often lack engagement and fail to promote deep understanding, leading to calls for more interactive approaches especially in chemistry (Dy et al., 2024). One of the used simulations that has taken a widespread attention in learning and especially in chemistry is the PhET interactive simulation (Kizito & Hassan, 2024). PhET simulations, developed by the University of Colorado, provide visual, real-life, and engaging tools that support both individual and group learning across scientific disciplines (Clark & Chamberlain, 2014; Kizito & Hassan, 2024). Their ability to visualize abstract ideas enhances conceptual understanding and motivation (Sa'diyah & Lutfi, 2023; Correia et al., 2018). This study examines the impact of the "Reactants, Products, and Leftovers" PhET simulation on tenth graders' understanding and attitudes toward chemical reactions.

1.1. Theoretical framework

1.1.1. Experiential learning theory

Kolb's experiential learning theory (1984) emphasizes that knowledge is created through active interaction between the learner and their environment (Sætren et al., 2021). It suggests learning is more effective when learners actively create and recreate knowledge rather than passively receiving information (Bergsteiner et al., 2010). The theory follows a cycle of four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation (Sætren et al., 2021).

In this study, students first engage in the concrete experience by using the PhET "Reactants, Products and Leftovers" simulation. Next, they reflect on their experience through guided questions (reflective observation). Then, they connect what they observed with real-life examples and teacher guidance to form abstract concepts (abstract conceptualization). Finally, students apply their understanding by practicing related exercises, completing the cycle with active experimentation.

1.1.2. Behaviorism learning theory

This learning theory focuses on learners' reactions to external stimuli and observable behavior rather than internal thoughts or emotions. It emphasizes that learning occurs through changes in students' visible performance (Ross , 2021). Since attitude reflects such observable changes, there is a clear link between learning outcomes and attitude (Ross , 2021). In this study, real-life features like the sandwich example and interactive games in PhET simulations make learning enjoyable, fostering positive behavioral changes and deeper understanding of chemical reactions.

1.2. Purpose

The purpose of this research is to:

- Examine the impact of using "reactants, products and leftovers" in PhET interactive simulation on improving grade 10 students understanding while learning chemical reactions compared with the traditional methods of teaching.
- Examine the impact of using "reactants, products and leftovers" in PhET interactive simulation on improving tenth graders' attitudes while learning chemical reactions compared with the traditional methods of teaching.

Research questions

- What is the impact of using "reactants, products and leftovers" in PhET interactive simulations on tenth graders' conceptual understanding while learning chemical reactions compared with the traditional methods of teaching?

- What is the impact of using “reactants, products and leftovers” in PhET interactive simulations on tenth graders’ attitude while learning chemical reactions compared with the traditional methods of teaching?

1.3. Hypotheses

- Hypothesis 1: Using “Reactants, Products and leftovers” simulation will significantly improve tenth graders’ conceptual understanding while learning chemical reactions compared with traditional methods of teaching.
- Hypothesis 2: The usage of “reactants, products and leftovers” in PhET interactive simulations will positively improve tenth graders’ attitude while learning chemical reactions compared with traditional methods of teaching.

2.1. Chemical reactions

Chemical reactions are abstract concepts involving macroscopic, submicroscopic, and symbolic levels, requiring students to observe phenomena, explain matter composition, and interpret chemical equations (Meliniasari & Setyarini, 2024). Many students struggle to connect the microscopic and submicroscopic levels, specifically while using the traditional methods of teaching and this hinders their understanding (Chandrasegaran, Treagust, & Mocerino, 2009; Abdoolatiff & Narod, 2009). Despite being foundational for advanced topics like equilibrium and acids-bases, chemical reactions remain challenging due to students’ difficulty visualizing molecular interactions (Salame & Makki, 2021). Thus, interactive simulations are essential for helping students visualize and simplify these abstract concepts.

2.2. Simulation-based-learning (PhET simulation)

Simulations are technologies that replicate real-life scenarios for learning (Beaubien & Baker, 2004). (Chandrasegaran et al., 2009) define them as interactive tools enabling learners to engage physically with modeled experiences. Their educational value includes immediate feedback, visual representation, and exposure to rare situations, all enhancing learning (

Hattie & Timperley, 2007). This study used the PhET simulation especially "reactants, products and leftovers" simulation, developed by the University of Colorado, which offers free interactive tools in chemistry, physics, and biology to support individual and group learning. (Haryadi & Pujiastuti, 2020). PhET simulations help students visualize abstract concepts like chemical reactions, and Meliniasari and Setyarini (2024) found they significantly improve understanding of chemical reaction representations (Meliniasari & Setyarini, 2024).

2.3. Conceptual understanding

Alao and Guthrie (1999) define conceptual understanding as deep and broad knowledge that connects concepts across different areas (Nieswandt, 2007). In chemistry, this means grasping how substances and particles interact, which is essential since chemical reactions relate to topics like equilibrium and reaction rates (Holme et al., 2015). Educational simulations, such as PhET, have been shown to improve students' conceptual understanding more effectively than traditional methods (Kizito & Hassan, 2024). As revealed by the results of the study titled "Examining the Use of PhET Simulations on Students' Attitudes and Learning in General Chemistry II" conducted by Salame and Makki (2021) that PhET simulations helped students learn abstract chemistry concepts better (Salame & Makki, 2021).

2.4. Attitude

Simulations have a benefit in fostering positive attitude while learning (Kizito & Hassan, 2024). Attitudes are learned tendencies to react and can change predictably (Zimbardo & Leippe, 1991; Simonson & Maushak, 2001). It is also known as students' affective expressions as positive or negative toward subjects like chemistry (Morrell & Lederman, 2010). Students often have negative attitudes toward chemistry due to traditional memorization-based teaching (Chua & Karpudewan, 2017). However, Salame and Makki (2021) found that using PhET simulations improved students' attitudes (Salame & Makki, 2021).Since few studies focus on both cognitive and affective aspects especially with the

"Reactants, Products and Leftovers" PhET simulation. I will explore how these sides influence learning. 3: Methodology

3.1. Research design

A mixed-methods approach was employed including quantitative tools (two posttests and questionnaire) and qualitative tools (interview questions and observation grid) to gather a deeper data from this small sample size as evidence to either accept or reject the mentioned hypotheses in the first chapter.

3.2. Instruments

The PhET simulation "Reactants, Products and Leftovers" was used with tenth graders to help visualize the abstract concept of chemical reactions. Students accessed the simulation freely on their smartphones.

Two posttests were administered to assess their conceptual understanding after both traditional teaching and simulation use.

A questionnaire was given after the simulation to gather students' attitudes about their learning experience.

Interviews were conducted with three students, selected for low, medium, and high chemistry performance, to gain deeper insights into their reflections on both teaching methods.

An observation grid was used to record students' interactions with the simulation, focusing on its features, design, and students' expressions.

The instruments will be presented in the Appendix.

3.3. Sample

This study involved ten tenth graders, aged 15–16, from various private and public schools in Lebanon, gathered at a center in Beirut. They had diverse academic performance and chemistry knowledge to assess the overall effectiveness of the simulation. The research uses data triangulation, combining quantitative and qualitative methods, collecting data from students and teacher observations to understand the simulation's impact on conceptual understanding and attitudes. Research questions are aligned with the tools' questions (see appendix) to ensure validity and reliability.

3.4. Validity of instruments

The questionnaire and interview questions were carefully aligned with the research questions and reviewed by three experts in the field to ensure validity and provide triangulation. Reviewers commonly suggested including the name of the simulation in the questionnaire, using checkboxes for responses, and adding "other" option for some questions. For the interview, feedback focused on making questions open-ended and limiting them to a maximum of six to keep them clear and concise. Additionally, tests designed around the research questions were reviewed by chemistry teachers and coordinators to offer multiple perspectives, further strengthening the study's validity.

3.5. Reliability of instruments

3.5.1. For quantitative data

The tests and questionnaire's reliability were assessed using Cronbach's alpha method, ensuring a reliability coefficient > 0.6 and repeated non-consecutive intervals for accurate results.

- Questionnaire

Table 1 Testing the reliability of the questionnaire

Reliability Statistics

Cronbach's Alpha	N of Items
.507	9

Since Cronbach's alpha= 0.507< 0.6 then the questionnaire was not found to be reliable likely due to the small sample size and time limitations when conducting this study.

- Tests

Table 2 Testing the reliability of the post-tests

Reliability Statistics

Cronbach's Alpha	N of Items
.148	11

Since Cronbach alpha = 0.148 < 0.6 then the questions of the exam were not found to be reliable, likely due to the small sample size and time limitations when conducting this study.

3.6. Permissions

- Permission from the principle of the center: The principal's explicit consent to conduct the intervention was obtained in advance. The signed consent form was scanned and is included in Appendix E.

- Parental permission: Parents gave their consent for their children’s participation. The parental assent form for first-year secondary students was created using Google Forms and is shown in Appendix F

3.7. Ethical concerns

Researchers that conduct educational research are limited by ethical standards that protect the rights of participants (Hendricks, 2017). These standards include an acceptance from the participants with an emphasis that their identity won’t be shared, an insurance that the participants will not be harmed or deceived and a maintenance of confidentially for participants collected data that will be used in a responsible manner and not be modified. In addition to that, a small description of the research was presented to the center’s principle to maintain transparency before applying this study.

3.8. Limitations

The study’s small sample size limits the significance of the PhET simulation’s impact. Poor internet connectivity and the cost of installing the application restricted the implementation phase. Since I conducted the study myself, students may have felt hesitant to answer tests freely, potentially introducing bias. Additionally, the study was limited to one week, which may have prevented the full impact of the simulation from emerging.

3.9. Procedure of the study

This study utilized pre- and post-tests, questionnaires, semi-structured interviews, and observation grids to assess students' understanding of chemical reactions and their opinions on teaching strategies were in alignment with the study goals.

A group of specialists in scientific education has reviewed the instruments to guarantee content validity and appropriateness. The tools' final iterations incorporated constructive criticism that was offered. Additionally, the study received the required ethical approvals: formal authorization was obtained from the educational center's administration, and parents' informed permission was gathered through digital forms provided via WhatsApp (Appendix A).

Students were first introduced to the idea of chemical reactions utilizing standard classroom techniques as part of the instructional intervention's typical teaching approach. After this stage, students were given a post-test to gauge their comprehension using the conventional method (Appendix B).

In the next stage, the PhET platform's interactive simulation "Reactants, Products, and Leftovers" was presented to the students. Students were given brief instructions to encourage individual inquiry before they began the simulation (Appendix C). Using the pre-made observation grid, the researcher conducted organized classroom observations as students engaged with the simulation to record behaviors and degrees of involvement (Appendix D). Students took the same post-test to gauge their conceptual grasp of chemical reactions after using the digital tool after completing the simulation-based instruction (Appendix E). A Google Forms-based survey was sent electronically to all participants in order to gather their thoughts on the educational process in order to supplement the quantitative data (Appendix F). Additionally, three students representing a range of chemistry academic achievement levels participated in semi-structured interviews. For qualitative analysis, these interviews were audio recorded (Appendix G).

All of the data that had been gathered had finally been methodically arranged for analysis. The Statistical Package for the Social Sciences (SPSS) was used to evaluate the quantitative data from the pre- and post-tests. Pairwise t-tests were used to assess the significance of conceptual comprehension differences between the simulation-based and traditional teaching approaches. Questionnaire and interview qualitative data were subjected to thematic analysis. To do this, graphical response trends were examined, and the recorded interview transcripts were coded in order to identify recurring themes and insights about the learning experiences of the students.

Chapter 4: Result and Analysis

The study's main findings are presented and analyzed, organized thematically and supported by data, providing a deeper understanding of observed patterns, trends, and implications.

4.1. Interview Analysis

To complement the quantitative findings, semi-structured interviews were conducted with three participants selected based on their educational levels (low, medium, and high). The interviews aimed to explore students' perceptions of learning chemical equations using the *PhET "Reactants, Products, and Leftovers"* simulation compared to traditional instructional methods.

In response to the first question— *"How does the simulation help you understand chemical equations compared to traditional methods?"*—all participants reported that the simulation significantly enhanced their comprehension. They specifically noted that the visual representation of atoms in reactants and products made abstract concepts, such as limiting reactants and leftovers, easier to grasp. In contrast, traditional methods were described as less effective in helping them visualize atomic interactions.

Regarding the second question on knowledge gains, participants emphasized that the concept of leftovers, previously unclear, became more accessible through the simulation. They found that observing the consumption of reactants and the formation of excess material visually clarified a concept they had struggled with in traditional board-based instruction. Similarly, the idea of a limiting reactant was better understood through interactive elements and visual cues.

When asked what they enjoyed most, all three participants highlighted the simulation's game-like and engaging nature. They agreed that the interactive format increased their motivation and attention during learning, unlike conventional approaches.

As for the most helpful feature, two participants pointed to the real-life analogy of sandwich-making as a key strength, stating it helped them understand abstract chemical processes. The third participant emphasized the clarity provided by atomic-level visuals.

Challenges were also noted: two participants mentioned internet limitations that hindered full exploration of the simulation, while one indicated a need for more teacher support to use the tool effectively. Despite these difficulties, all participants described the experience as positive and recommended a blended approach that integrates both simulation and traditional teaching to maximize understanding.

These qualitative insights align with the test data and support the conclusion that the simulation is a valuable pedagogical tool for enhancing conceptual learning in chemistry

4.2. Observation Analysis

When compared to conventional teaching techniques, the "Reactants, Products, and Leftovers" simulation dramatically increased students' comprehension and involvement, according to the observation checklist. With the help of the "Sandwiches" simulation, which made complex topics easier to understand, students were able to more successfully explain important concepts like limiting reagents and leftovers.

Students actively participated in the simulation by experimenting with different combinations and posing more in-depth queries, both of which are indications of significant cognitive engagement. Their questionnaire answers revealed a generally favorable opinion of the exercise, suggesting that it was both entertaining and instructive.

Some students, however, need more instruction, particularly in the interpretation of coefficients and the comprehension of particular words like "reactants" and "leftovers." Even though the simulation cleared up a number of myths about conventional approaches, it was evident that instructor assistance was still necessary to optimize its efficacy. The observer also mentioned how crucial dependable internet access is to a successful implementation.

All things considered, if the simulation is accompanied by appropriate resources and structured coaching, it can be a useful tool for improving conceptual comprehension.

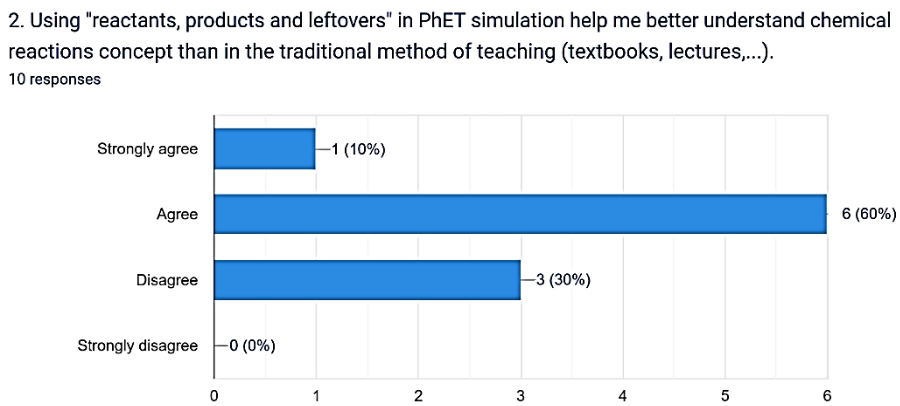
4.3. Questionnaire analysis

"The main questions selected for analysis were chosen based on their direct relevance to the study's objectives, particularly in assessing students' conceptual understanding, engagement, and perceptions of the simulation compared to traditional methods."

Figure 1 Students past experience toward the PhET simulation.

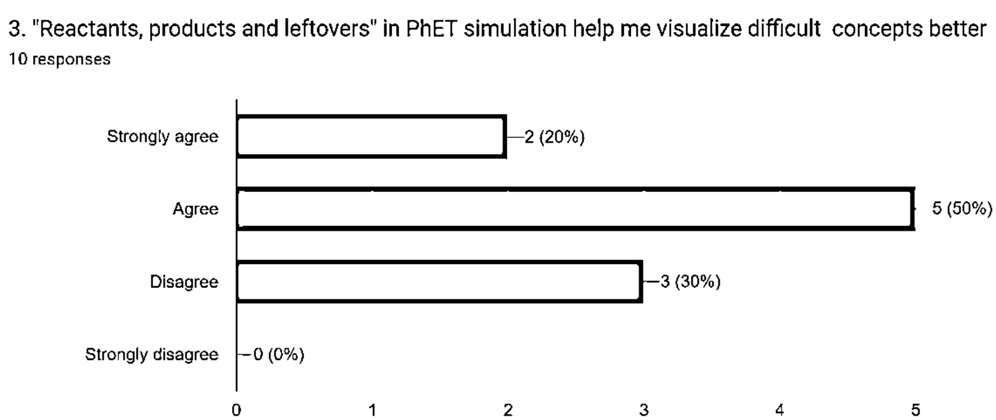
The graph shows that 100% of students haven't used PhET before.

Figure 2 Students response regarding "Reactants, Products and Leftovers" simulation in improving their conceptual understanding compared to traditional methods.



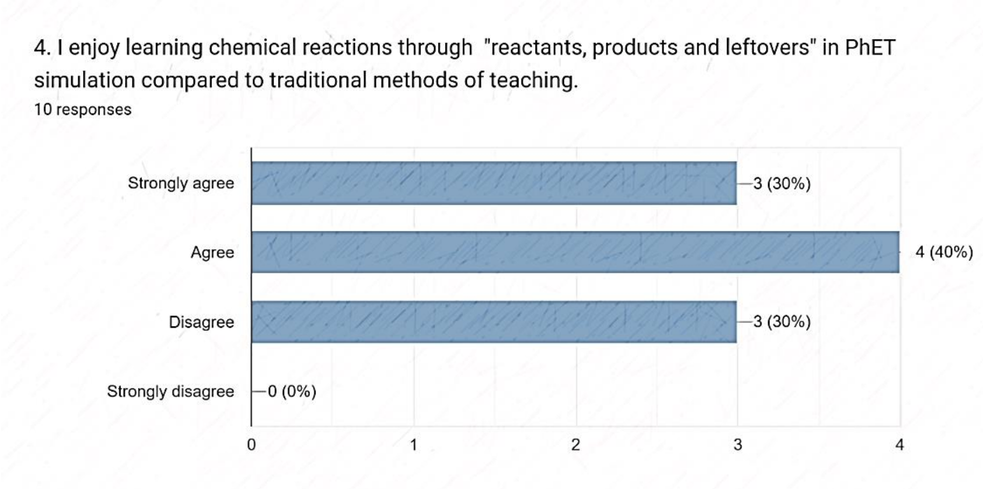
The graph indicates that a majority of students (60%) agreed that using the *Reactants, Products, and Leftovers* simulation in PhET enhanced their understanding of chemical reactions compared to traditional methods. Additionally, 10% strongly agreed with this view, while 30% disagreed. Notably, no students strongly disagreed, suggesting an overall positive prception of the simulation's effectiveness.

Figure 3 Students response regarding the usage of "Reactants, Products and Leftovers" simulation in visualizing difficult concepts.



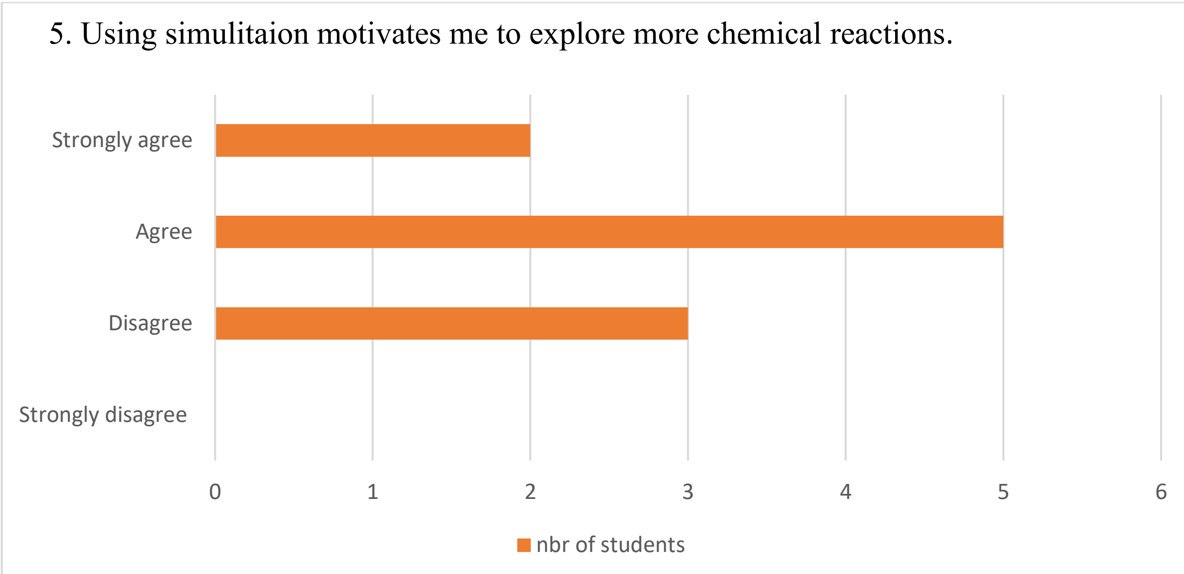
The data shows that 70% of students (20% strongly agreeing and 50% agreeing) felt that the simulation effectively aided in visualizing complex concepts. Although 30% expressed disagreement, the absence of strong disagreement suggests a generally positive perception of the simulation's role in enhancing conceptual understanding.

Figure 4 Students response regarding the usage of "Reactants, Products and Leftovers" simulation in making students enjoy learning chemical reactions compared to traditional methods.



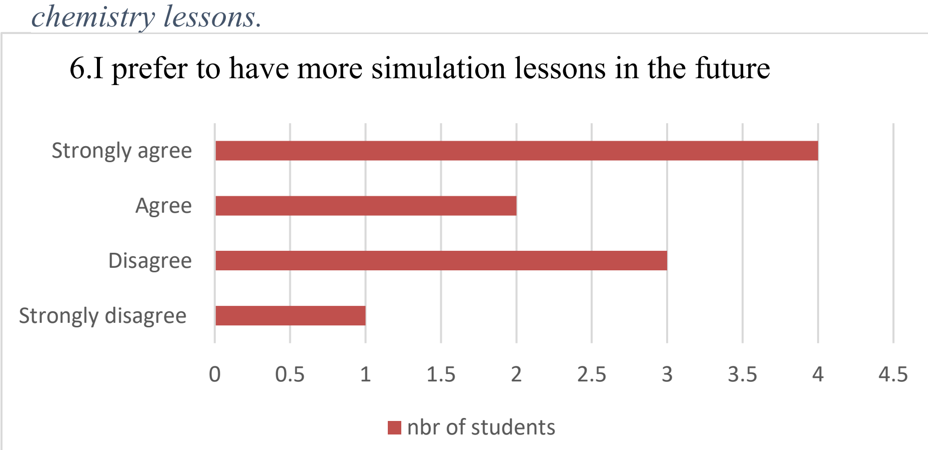
The results indicate that 70% of students (30% strongly agree, 40% agree) reported enjoying learning through the *Reactants, Products, and Leftovers* PhET simulation. Only 30% disagreed, and no students strongly disagreed, reflecting an overall positive engagement with the simulation-based learning approach.

Figure 5 Students response regarding the usage of "Reactants, Products and Leftovers" simulation in motivating students for exploring more about chemical reactions.



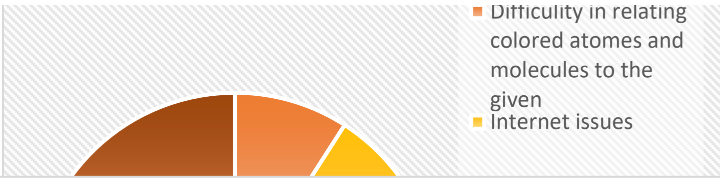
The graph shows that 70% of students (20% strongly agree, 50% agree) feel motivated to explore more chemical reactions through the simulation, while 30% disagreed. No students strongly disagreed, indicating a generally positive impact on student motivation.

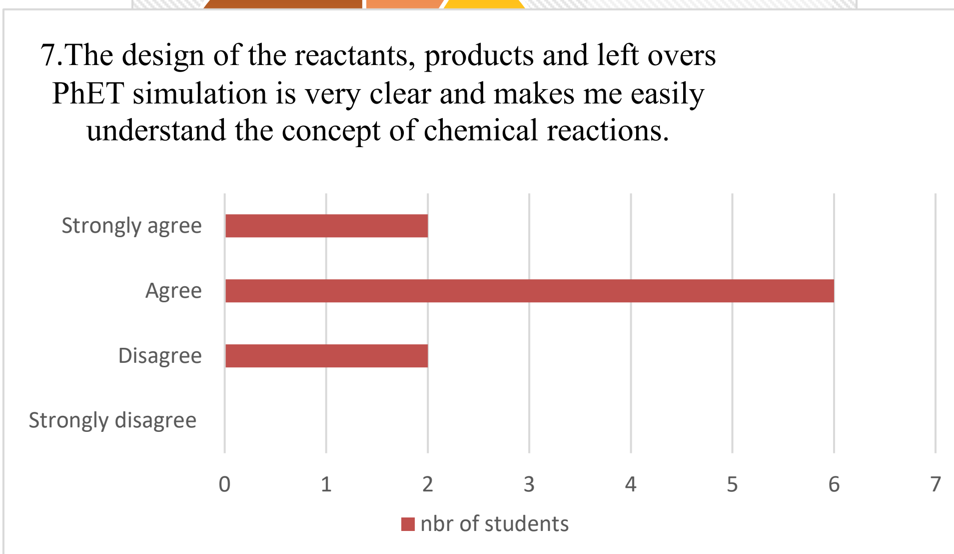
Figure 6 Students response regarding the usage of simulations in future chemistry lessons.



The data shows that 60% of students (40% strongly agree, 20% agree) had a positive view, while 40% (30% disagree, 10% strongly disagree) expressed negative perceptions.

Figure 7 Students response regarding the design of "Reactants, Products and Leftovers" simulation.



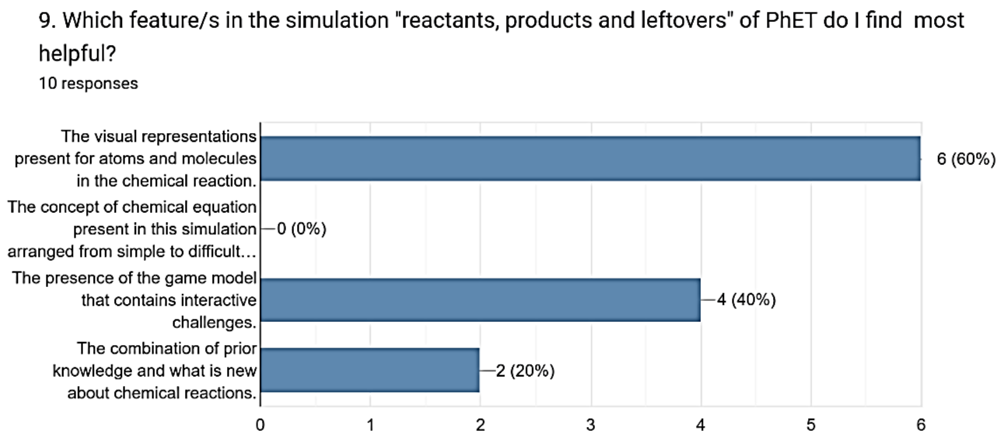


The graph shows that 80% of students (6 agree, 2 strongly agree) found the design of the PhET simulation clear and helpful in understanding chemical reactions. Only 20% (2 disagree) expressed a negative view.

Figure 8 Students response regarding the challenges they faced while using "Reactants, Products and Leftovers" simulation.

The data reveals that 60% of students encountered challenges while using the simulation, such as internet connectivity issues, difficulty interpreting color-coded atoms and molecules, and the need for teacher support to navigate the tool. Meanwhile, 40% of students found the simulation easy to use, suggesting that while it is generally user-friendly, effective implementation may require guided instruction and stable access conditions.

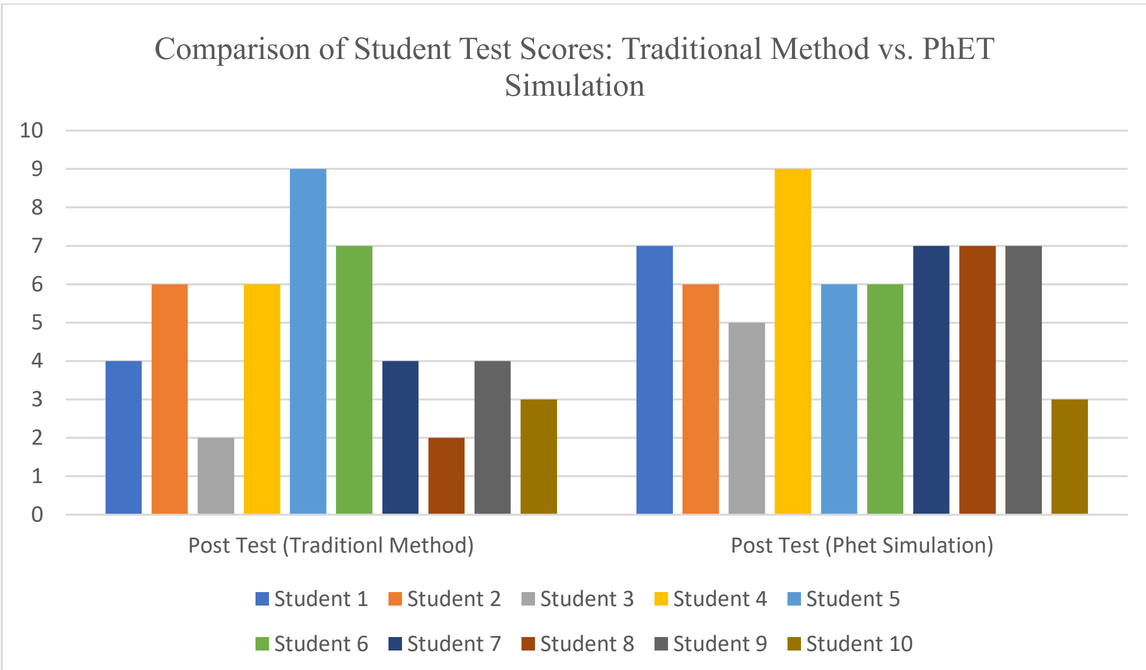
Figure 9 Students response regarding the mostly helpful features of "Reactants, Products and Leftovers".



The graph indicates that 60% of students found the visual representation of atoms the most helpful feature in understanding chemical equations. Additionally, 40% valued the inclusion of game-like modules, while 20% appreciated the integration of prior knowledge. These results highlight the importance of interactive visuals and engaging elements in facilitating conceptual learning.

4.4. Tests Analysis

Figure 10 Comparison of students test scores: traditional method vs. PhET simulation.



The graph comparing post-test scores shows a consistent improvement in student performance when using the PhET simulation. While scores from the traditional method range widely (from 2 to 9), the simulation scores are more concentrated between 6 and 7, indicating greater consistency and overall higher achievement.

- 60% of students scored higher using the simulation than with the traditional method.
- 20% scored the same in both methods.
- 20% performed better with the traditional method.

4.4.1. Normality test

Table 3 Normality test for post-tests.

Tests of Normality							
	Students' numbers	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	Df	Sig.	Statistic	df	Sig.
Post test (using traditional method of teaching) for assessing conceptual understanding.	Student	.221	10	.180	.930	10	.453
Post test (using the simulation in PhET) for assessing conceptual understanding.	Student	.228	10	.152	.907	10	.262
a. Lilliefors Significance Correction							

- According to Shapiro- Wilk:

- Normality was confirmed for both post-test groups ($p > 0.05$), justifying the use of a paired sample t-test.

4.4.2. Paired Samples Test

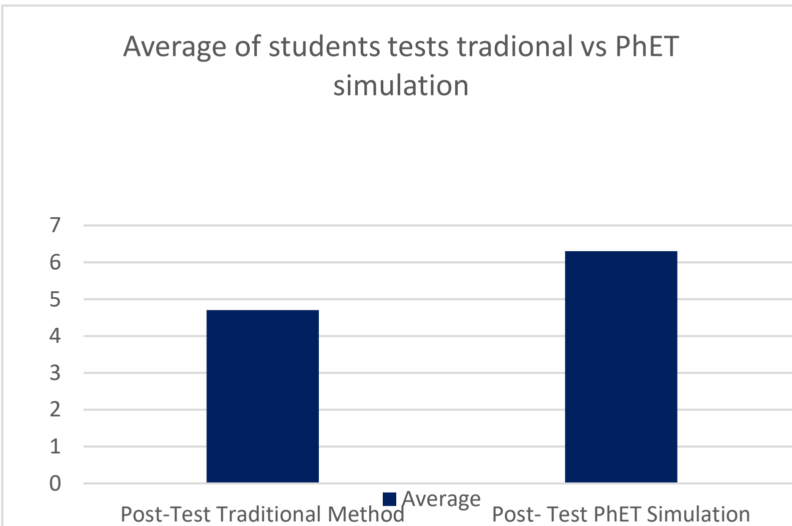
Table 4 Paired samples test for post-tests.

Paired Samples Test									
		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	Upper	T	df	Sig. (2-tailed)
Pair 1	Post test (using traditional method of teaching) for assessing conceptual understanding. - Post test (using the simulation in PhET) for assessing conceptual understanding.	-1.600	2.459	.777	-3.359	.159	-2.058	9	.070

No significant difference was found (p= 0.070), indicating that the PhET simulation had no significant impact on conceptual understanding.

4.4.3. Average of the tests

Figure 11 Average of students' tests: traditional vs. PhET



The graph demonstrates how the PhET simulation significantly raised students' average performance. The average post-test score rose from 4.7 with traditional instruction to 6.3 with the simulation, suggesting that interactive, visual-based learning has improved conceptual understanding.

4.5. General Analysis of Findings

The PhET Reactants, Products, and Leftovers simulation enhances students' conceptual comprehension of chemical equations, demonstrating better engagement and motivation compared to conventional teaching methods.

Students said that abstract chemical concepts, like limiting reactants and leftovers, were easier to understand thanks to the simulation's interactive and visual elements. A more engaging and concentrated learning process was also facilitated by the addition of game-based components and real-world comparisons. The study found that students felt that the simulation enhanced their comprehension and visualization of complex interactions, and scored higher on the simulation-based post-test compared to the conventional one.

Notwithstanding these benefits, a few drawbacks were identified, such as technological difficulties (such internet access) and the requirement for instructor assistance when using the simulation on one's own. According to these results, the tool works well, but its effects are amplified when used in a mixed learning setting that blends teacher-led instruction and simulation.

The simulation enhances engagement but shows limited impact on conceptual understanding of chemical reactions.

Chapter 5: Conclusion, Limitations, Implications and Recommendations

5.1. Conclusion

This study sought to evaluate the effects of traditional teaching techniques with the use of the PhET interactive simulation "Reactants, Products and Leftovers" on the knowledge and attitudes of tenth graders regarding chemical reactions. The interactive simulations enhanced students' understanding and attitudes towards chemical reactions, boosting enthusiasm and motivation, supporting predictions that interactive simulations can enhance learning outcomes and student involvement in chemistry education.

5.2. Limitations

The small sample size limits the application of results to conceptual knowledge, and the intervention's duration may not significantly alter students' motivation or understanding of complex chemistry concepts.

5.3. Implications

The study offers valuable insights for educators, students, and policymakers on how interactive simulations like PhET can enhance students' comprehension and foster positive learning attitudes. The study suggests that incorporating technologically enhanced learning resources in science education can lead to better participation, academic achievement, and increased motivation, thereby promoting a more comprehensive approach to learnin

5.4. Recommendations

5.4.1. Parents

- Encourage a love of science by talking about ideas and investigating simulations with others.
- Keep an eye on and make sure screen time is balanced while encouraging interest in science.
- Encourage and assist your kids in using educational simulations as an adjunct to conventional classroom instruction.

5.4.2. Curriculum Developers and Technical Teachers

- Develop curriculum-relevant, user-friendly simulations that accommodate varying learning levels in partnership with software developers.
- Utilize instructor and student input to enhance the usability and content of simulations over time.
- Create courses that incorporate interactive online resources that are in line with chemistry learning goals.

5.4.3. For Learners

- To improve your comprehension of abstract chemistry concepts, actively participate in interactive simulations such as PhET.

- Beyond the classroom, investigate and experiment with chemical reactions using simulations as a self-paced learning tool.
- Communicate your challenges and experiences to educators in order to enhance simulation-based learning.

5.4.4. School Leaders

- Make dependable technology and internet infrastructure more accessible to enable simulation-based learning.
- Give educators opportunities for professional growth so they can successfully include simulations into their lesson plans.
- To improve student learning, promote a school culture that values cutting-edge teaching resources.

The findings of this study emphasize the importance of integrating interactive digital tools like PhET simulations in science education to enhance both students' understanding and attitudes toward complex concepts such as chemical reactions. This research supports the hypothesis that using the "Reactants, Products and Leftovers" simulation improves tenth graders' learning outcomes compared with traditional teaching methods.

Research and collaboration among educators, curriculum developers, and policymakers are crucial for exploring digital simulations' potential in various science topics and grade levels. By applying these insights, education systems can better harness technology to foster deeper conceptual learning and positive student engagement.

If the use of PhET simulations significantly enhances tenth graders' understanding and attitudes in chemistry, how might the integration of similar interactive tools impact learning and motivation in other scientific disciplines and age groups?

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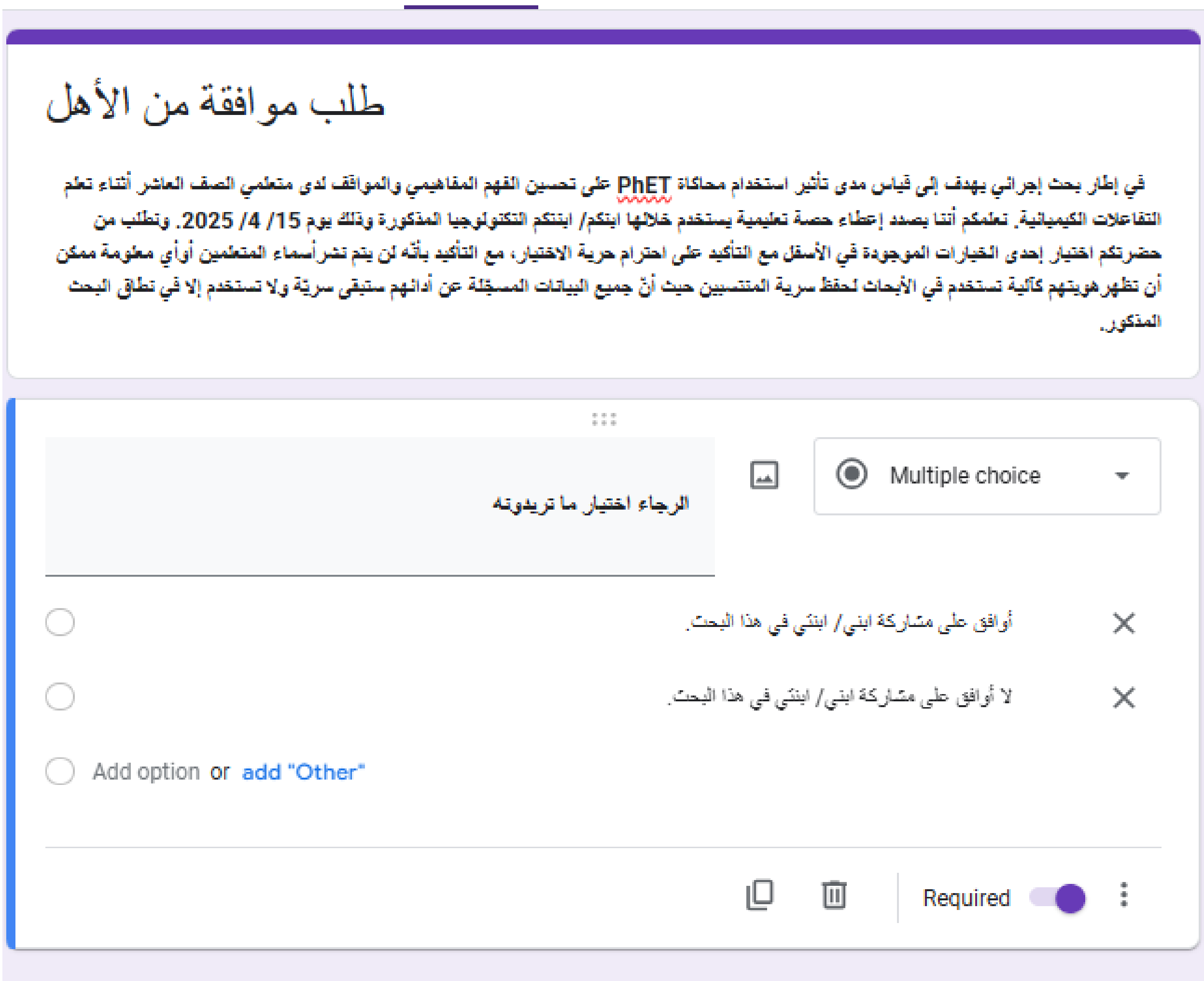
Appendices

Appendix A – Assent form for parents of the first-year students



طلب موافقة من الأهل

في إطار بحث إجرائي يهدف إلى قياس مدى تأثير استخدام محاكاة PhET على تحسين الفهم المفاهيمي والمواقف لدى متعلمي الصف العاشر أثناء تعلم التفاعلات الكيميائية. تعلمكم أننا بصدد إعطاء حصة تعليمية يستخدم خلالها ابنكم/ ابنتكم التكنولوجيا المذكورة وذلك يوم 15/ 4/ 2025. وتطلب من حضرتكم اختيار إحدى الخيارات الموجودة في الأسفل مع التأكيد على احترام حرية الاختيار، مع التأكيد بأنّه لن يتم نشر أسماء المتعلمين أو أي معلومة ممكن أن تظهر هويتهم كآلية تستخدم في الأبحاث لحفظ سرية المتنسبين حيث أنّ جميع البيانات المسجّلة عن أدائهم ستبقى سريّة ولا تستخدم إلا في نطاق البحث المذكور.

الرجاء اختيار ما تريدونه

Multiple choice

أوافق على مشاركة ابني/ ابنتي في هذا البحث.

لا أوافق على مشاركة ابني/ ابنتي في هذا البحث.

Add option or add "Other"

Required

Appendix B – Posttest (after the traditional method of teaching)

Date:

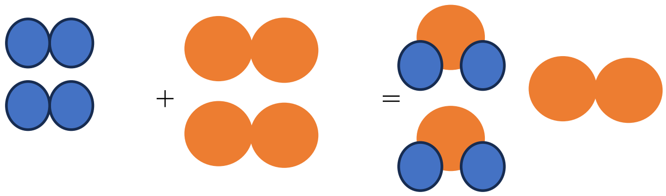
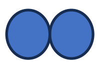
Post test 1

Time: 10 mins

Question 1

Choose the **correct answer**:

1. What does a balanced chemical equation mean? a. The number of atoms or molecules in both reactants and products is not conserved. b. The number of atoms or molecules in both reactants and products is conserved. c. The number of moles of reactants is equal to the number of moles of the products. d. None of the above.	2. Which of the following statements is correct one concerning the role of the balanced equation? a. It indicates how many product/s should be produced. b. It indicates how many reactants should be reacted. c. It provides the most suitable reactant ratio to produce the most product. d. It predicts which atoms will be left over.
3. If you are making sandwiches of cheese, and you have 6 toast and 3 slices of cheese, how many slices of cheese will remain? a. 0.5 b. 0 c. 3 d. 1 Note that for each cheese you need 2 toast breads.	4. What does the limiting reactant mean? a. The reactant that will be totally consumed. b. The reactant that will disappear at the end of the reaction. c. The reactant that limits the amount of product/s produced. d. All of the above.
5. If one of the reactants is not totally consumed, then what will happen to the reactants at the end? a. Both reactants will disappear. b. The reactant that is not totally consumed will remain as leftover. c. The reactant that is not totally consumed will transform into a product. d. Part of the reactant that is not totally consumed will be formed as a product and the other part will remain as an excess.	6. According to this reaction: $N_2 + 3\ H_2 = 2\ NH_3$ If we have 2 molecules of N_2 and 6 molecules of H_2, how many Ammonia molecules (NH_3) will be produced? a. 2 b. 4 c. 6 d. 3

7. In the following document:  Where  is H_2 and  O_2 and the product is H_2O . Choose the correct explanation for the above reaction: a. 2 H_2 molecules react with 2 O_2 to give 2 H_2O with no left over. b. 2 H_2 react with 2 O_2 to give 2 H_2O with 2 O_2 left overs. c. 2 H_2 react with 2 O_2 to give 2 H_2O with 1 O_2 left over. d. None of the above.	8. In the following chemical reaction: 1 N_2 + 3 H_2 = 2 NH_3 , What will be the limiting reactant if 7 molecules of H_2 react with 2 molecules of N_2? a. The limiting is N_2 . b. The limiting is H_2 . c. No limiting reactant. d. None of the above.
9. What do we mean by ratio? a. The amount of leftover product after a reaction. b. The number of molecules formed. c. The energy released or used in the reaction. d. The proportion of reactants needed to fully react and form products.	10. If the ratio of reactants A and B is 1:3 and you use 5 molecules of reactant A, how many molecules will be needed to fully react with reactant A? a. 15 b. 5 c. 10 d. 3

Appendix C – Guidance/ Instruction sheet for using “Reactants, Products and Leftovers” simulation in PhET

To open PhET simulation.

Go to the PhET website: https://phet.colorado.edu/

Select on Chemistry while moving downward and search for “reactants, products and leftovers”.

Click on play and select the sandwiches.

Demonstrate the given equation as presented “2 breads + 1 pieces of cheese”.

Calculate the number of sandwiches that can be prepared using the specified amounts of ingredients.

Enter varying amounts of the ingredients.

Keep track of how many whole sandwiches are made and note any ingredients that are left over.

Questions for discussion:

1. What ingredient restricts or limits how many sandwiches you can prepare?
2. What impact does changing the amount of one ingredient have on the overall number of sandwiches made?

Now move to the next section “molecules”.

Demonstrate the given equation as presented “$2H_2$ + 1 O_2”

Modify the quantity of these reactants. Keep an eye out for any remaining reactants and note how the products are formed.

Questions (discussed):

1. What is the ratio of this reaction?
2. Which reactant in the reaction is the limiting factor?
3. What effect does the reactant ratio have on the amount of product that is produced?

Now move to the third section “game” and select level 1.

Select a game level from 1 to 3.
Predict how much products and leftovers will be needed to answer questions.

Get quick feedback on your responses.
Advice: If necessary, refer to the "Molecules" and "Sandwiches" screens.
Aim for a perfection score by making accurate predictions.

After completing the simulation:

1. How does the idea of a limiting reactant relate to chemical processes and sandwich-making?
2. Why is it important to know which reactant in a chemical reaction is limiting?
3. In how does this simulation help in the visualization of atom conservation during reactions?

Appendix D – Observation grid

Date: April 14th, 2025

Observation sheet

	Observed	Not observed	Notes:
1. Students explain the concept of limiting and leftovers while using "reactants, products and left overs".	✓		From the "Sandwiches" simulation presented in this simulation as they were the best real-life visual presented for this concept.
2. Students show positive attitude while using the simulation "reactants, products and left overs" compared to the traditional method.	✓		This was revealed from the questionnaire responses as most of them answered that it was an enjoyable experience.
3. Students actively explore the simulation (tries different combinations).	✓		Students have showed this point especially when playing the game presented in this simulation.

4. The usage of the simulation “reactants, products and left overs” improves students’ conceptual understanding toward chemical reactions especially ratios, limiting and left overs compared to traditional method.	✓		From the visuals presented as they were observing concepts hard to be shown or explained in traditional methods of teaching.
5. Students ask questions or show curiosity about what is happening in the simulation compared to traditional method of teaching.		✓	
6. The usage of the simulation “reactants, products and left overs” needs more guidance.	✓		Since students need to be directed for exactly what they should do and since in this study deep questions triggers deep conceptual understanding.
7. Students have a misunderstanding	✓		They have shown misunderstanding in the coefficients presented near each molecule.

observed in the traditional method.			
8. "Reactants, Products and Leftovers" simulation was able to solve the misunderstanding.	✓		By trying different numbers or coefficients for the atoms or the molecules they have seen the difference.

Observer comments: This simulation needs more guidance by the teacher and there must be a check for an internet as this simulation was not freely used when downloading the application.

Overall notes or Suggestions: This simulation was good in revealing the concepts through the visuals especially the sandwiches used. So, this simulation was beneficial in fostering a positive attitude while learning chemical reactions as I have seen students playing the game and enjoying the simulation of sandwiches.

Appendix E – Post test (after using the PhET simulation)

Date:

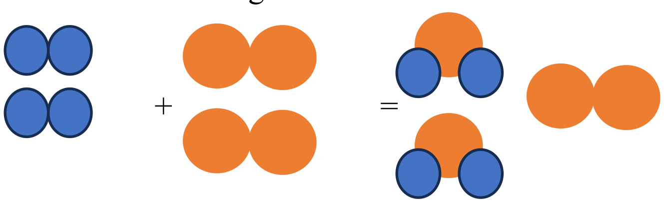
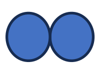
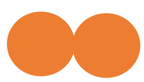
Post test 2

Time: 10 mins

Question 1

Choose the **correct answer**:

1. What does a balanced chemical equation mean? a. The number of moles of reactants is equal to the number of moles of the products. b. The number of atoms or molecules in both reactants and products is not conserved. c. The number of moles of reactants is equal to the number of moles of the products. d. None of the above.	2. If you are making sandwiches of cheese, were you have 6 toast bread and 3 slices of cheese. how many slices of cheese will remain? a. 0.5 b. 0 c. 3 d. 1 Note that for each cheese you need 2 toast breads.
3. What does a balanced chemical equation mean? a. The number of moles of reactants is equal to the number of moles of the products. b. The number of atoms or molecules in both reactants and products is not conserved. c. The number of moles of reactants is equal to the number of moles of the products. d. None of the above.	4. If the ratio of reactants A and B is 1:3 and you use 5 molecules of reactant A, how many molecules will be needed to fully react with reactant A? a. 5 b. 10 c. 15 d. 3
5. Which of the following statements is correct one concerning the role of the balanced equation?	6. If one of the reactants is not totally consumed, then what will happen to the reactants at the end?

a. It predicts which atoms will be leftover. b. It provides the most suitable reactant ratio to produce the most product. c. It indicates how many reactants should be reacted. d. It indicates how many product/s should be produced.	a. The reactant that is not totally consumed will transform into a product. b. The reactant that is not totally consumed will remain as left over. c. Part of the reactant that is not totally consumed will be formed as a product and the other part will remain as an excess. d. Both reactants will disappear.
7. In the following document:  Where  is H_2 and  O_2 and the product is H_2O . Choose the correct explanation for the above reaction: a. 2 H_2 react with 2 O_2 to give 2 H_2O with 1 O_2 left over. b. 2 H_2 molecules react with 2 O_2 to give 2 H_2O with no left over. c. 2 H_2 react with 2 O_2 to give 2 H_2O with 2 O_2 left overs. d. None of the above.	8. What do we mean by ratio? a. The amount of leftover product after a reaction. b. The proportion of reactants needed to fully react and form products. c. The energy released or used in the reaction. d. The number of molecules formed.
9. According to this reaction: $N_2 + 3\ H_2 = 2\ NH_3$ If we have 2 molecules of N_2 and 6 molecules of H_2, how many Ammonia molecules (NH_3) will be produced? a. 4 b. 6 c. 3 d. 2	10. What does the limiting reactant mean? a. The reactant that limits the amount of product/s produced. b. The reactant that will be totally consumed. c. The reactant that will disappear at the end of the reaction. d. All of the above.

Appendix F – Google Forms Questionnaire (after using the simulation)

A Survey to Examine The Impact of PhET Simulation on Conceptual Understanding and Attitude of Tenth Graders Toward Chemical Reactions.

Dear tenth graders,
I am conducting this survey to find out how students like you use "reactants, products and leftovers" in PhET simulations to study Chemistry especially while studying chemical reactions. Your attitude on how this simulation aid in your studies, if it enhances your learning, if it motivates you and any difficulties you may have when utilizing them are the main goals of this survey. The survey will only take a few minutes to complete, and your answers will remain anonymous. I appreciate your time and insightful comments. Thank you in advance.

* Indicates required question

1. Have you used PhET simulation before? *

- ○ Yes
- ○ No

Students' experience while using "reactants, products and leftovers" in PhET simulation.

2. Using "reactants, products and leftovers" in PhET simulation help me better understand chemical reactions concept than in the traditional method of teaching (textbooks, lectures,...). *

- ☐ Strongly agree
- ☐ Agree
- ☐ Disagree
- ☐ Strongly disagree

3. "Reactants, products and leftovers" in PhET simulation help me visualize difficult concepts better *

- ☐ Strongly agree
- ☐ Agree
- ☐ Disagree
- ☐ Strongly disagree

4. I enjoy learning chemical reactions through "reactants, products and leftovers" in PhET simulation compared to traditional methods of teaching. *

- ☐ Strongly agree
- ☐ Agree
- ☐ Disagree
- ☐ Strongly disagree

5. Using simulations motivate me to explore more about chemical reactions and chemistry concepts. *

- ☐ Strongly agree
- ☐ Agree
- ☐ Disagree
- ☐ Strongly disagree

6. I prefer to have more lessons with simulations in the future. *

- ☐ Strongly agree
- ☐ Agree
- ☐ Disagree
- ☐ Strongly disagree

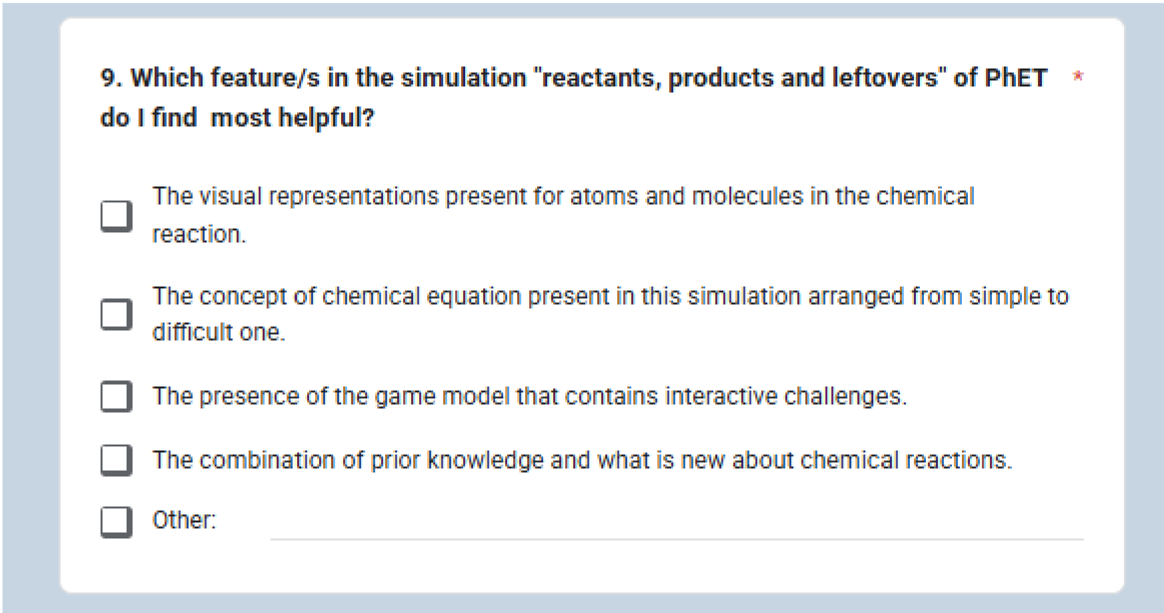
The features of "reactants, products and leftovers" in PhET simulation.

7. The design of "reactants, products and leftovers" in PhET simulation is very clear and it is makes me easily understand the concept of chemical reactions. *

- ☐ Strongly agree
- ☐ Agree
- ☐ Disagree
- ☐ Strongly disagree

8. What is/ are the challenge/s that I have faced while using " reactants, products and leftovers" in PhET simulation? *

- ☐ Difficulty in relating the colored atoms and molecules to the given chemical formulas.
- ☐ Internet issues.
- ☐ Hard to be used alone and needs teacher's guidance.
- ☐ None, it was easy to be used.
- ☐ Other: ______



9. Which feature/s in the simulation "reactants, products and leftovers" of PhET do I find most helpful? *

- [ ] The visual representations present for atoms and molecules in the chemical reaction.
- [ ] The concept of chemical equation present in this simulation arranged from simple to difficult one.
- [ ] The presence of the game model that contains interactive challenges.
- [ ] The combination of prior knowledge and what is new about chemical reactions.
- [ ] Other: ____________

Appendix G – Tenth Graders Semi-Structured Interview Questions

1. How does the usage of “reactants, products and leftovers” simulation in PhET make you understand chemical equation concept compared with the traditional methods of teaching?
2. What are the changes that “reactants, products and leftovers” simulation in PhET has added to your knowledge about chemical equation concept? Explain.
3. What do you enjoy mostly when using “reactants, products and leftovers” simulation in PhET compared to the traditional method of teaching while learning chemical equation concept?
4. Which of the features of “reactants, products and leftovers” simulation in PhET was mostly helpful? And how it helped you while learning?
5. Are there any difficulties you have faced while using “reactants, products and leftovers” simulation in PhET? If yes, what are they?