Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #47555

BOARD # 41: Enhancing Student Engagement and Learning Outcomes: Comparing Interactive Simulations with Traditional Clicker Questions in Introductory Engineering Courses

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Ehsan is a Teaching faculty at CU Boulder. He has taught at private and public schools for more than a decade. He always explores new tools for teaching such as immersive simulation, mixed-reality modules, and in here, he is presenting his use of 2.5 D simulations for teaching introductory concepts in freshmen and sophomore level chemical engineering courses.

Enhancing Student Engagement: Comparing Interactive Simulations with Traditional Clicker Questions in Introductory Engineering Courses

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ABSTRACT: This study explores the integration of Physics Education Technology (PhET) simulations into clicker-based activities to improve student engagement and learning in introductory chemical engineering courses. Conducted over multiple semesters in a General Chemistry for Engineers I course, the study compares traditional clicker (TC) questions with PhET simulation-based clickers, including both interactive (PhC) and instructor-led (PIC) formats. Key metrics—such as attendance, participation, response times, student performance, and live scores —were used to evaluate the effectiveness of these approaches.

Results show that incorporating simulations significantly improves attendance and participation, with faster response times observed for simulation-based questions. Mixed-clicker sessions, blending TC, PhC, and PIC, achieved higher overall engagement and grades compared to TC-only semesters. However, there is insufficient evidence to conclude that simulations alone outperform traditional questions in learning outcomes. The findings suggest simulations are more effective when used to construct understanding rather than as an assessment tool.

Rooted in constructivist learning theory and active learning principles, this work highlights the potential of combining dynamic, visual tools with traditional methods to foster deeper understanding in STEM education. Future research will investigate mixed-reality modules, topic-specific impacts of simulations on assessments, and the role of user engagement data in optimizing these technologies.

Introduction and Background

Improving engagement and learning outcomes in academia especially in introductory courses is essential for several interconnected reasons. These courses often serve as foundational stepping-stones that set the tone for a student's perception of the discipline. A strong start can foster confidence and motivation, while a lackluster experience may lead to disengagement or even attrition from the program. However, it is challenging to keep students engaged and attentive in this age and time using traditional teaching mediums such as boards and slide decks.[1] The abstract and sometimes intimidating nature of engineering concepts—such as thermodynamics, material balances, or reaction kinetics—requires teaching approaches that are accessible, impactful, engaging, and frankly exciting.

In this context, student engagement is more than a matter of participation; it directly correlates with how well students internalize and apply the material. Traditional lecture methods can struggle to keep students actively involved, especially in large classes where individual interaction is limited.[2,3] Without opportunities for hands-on exploration or dynamic feedback, students may find it difficult to connect theoretical concepts with their real-world applications. It is common to observe that the student perception is formed revolving around answering the exam and homework questions rather than understanding the phenomena.[4]

Learning outcomes are equally critical, as introductory courses lay the groundwork for advanced topics in the curriculum. Many institutions are closely monitoring these outcomes to assess the quality of the programs via third party evaluator namely ABET program. If students fail to grasp these fundamentals, their struggles may compound as they progress, leading to wider gaps in understanding. Beyond academic performance, these foundational skills are vital for their future roles as engineers, where problem-solving and the ability to interpret complex systems are daily requirements. It is common to address the gap between the theory and the practice through laboratory courses, however the total lab credit hours are small compared to total credit hours of a discipline pointing out the need for alternative solutions.

Clickers, aka classroom response systems (CRSs), have gained widespread popularity in education over the last two decades, particularly in large lecture-based settings.[5] There are numerous brands most notably Kahoot, Top Hat, and iClicker with different delivery platforms such as hardware, app, and web-based with some of these solutions offered under open-source licensing such as Pclickers and Google Forms. These polling tools allow instructors to pose questions during a lecture and receive immediate feedback from students, creating opportunities for active learning and formative assessment. **Formative assessment** is an ongoing, low-stakes evaluation process used during instruction to monitor student learning, provide immediate feedback, and guide teaching and learning.

The use of clickers has been shown to enhance student engagement by transforming passive lectures into interactive sessions. They encourage participation even among students who may feel hesitant to speak up in traditional settings, as responses are anonymous. Clickers also provide real-time insights into student understanding, enabling instructors to adjust their teaching on the fly. This immediate feedback loop is especially beneficial in STEM courses, where complex topics often require iterative explanation and practice. For example, in a general chemistry course, students usually find it challenging to understand the effect of a lone pair versus a bonding pair on a molecular geometry. This particular topic requires strong understanding of the spatial geometry from the students' side and effective 3D visuals from the instructor.

From the students' perspective, clickers can make class sessions more enjoyable and reduce the monotony often associated with long lectures. Additionally, they can reinforce learning by encouraging students to apply concepts immediately rather than waiting for homework or exams. Some research indicates that this active engagement can lead to improved retention and academic performance.[6] Despite the advantages, a minority of students are actually uninterested in clickers citing various reasons such as the distractive nature of these polling styles as well as stress-inducing format that these clickers could potentially result in. Over years, we have tried optimizing the use of clickers to make it a more pleasant user experience overall.

Additionally, student reception of clickers is highly dependent on how they are integrated into the course. In general, students tend to appreciate the interactive nature of clicker-based activities when they see a clear link to their learning outcomes. If used solely for attendance or low-stakes participation points, their potential as a learning tool diminishes. Students may perceive them as an unnecessary burden rather than a resource for enhancing their understanding which leads to frustration, citing them as disruptive or unhelpful.[7] To address these challenges and optimize the use of clickers, educators must thoughtfully design questions that align with course outcomes and promote critical thinking. Integrating clickers with other active learning strategies, such as group discussions or peer instruction, can further enhance their effectiveness.

PhET Simulations and Learning Styles

Given these challenges associated with CRSs, there is a growing need for instructional strategies that not only engage students but also enhance conceptual understanding in a meaningful way. By creating interactive and immersive learning environments, which enables the learner to take an active role in their learning, educators can address diverse learning styles and promote active participation, ultimately fostering both academic success and a lasting interest.

PhET (Physics Education Technology) simulations (sims) are interactive, research-based virtual tools designed to enhance learning in science, technology, engineering, and mathematics (STEM). Developed by the University of Colorado Boulder, these simulations allow students to visualize and manipulate scientific concepts in real-time. Covering a range of topics—from physics and chemistry to biology and mathematics—PhET simulations provide an engaging and exploratory learning environment.

PhET sims promote several learning styles: a. Active, b. Inquiry-based/Constructivist, and c. Differentiated. Their unique approach enables students to experiment with variables, test hypotheses, and observe the outcomes dynamically. Their intuitive, user-friendly interfaces make abstract concepts more tangible, helping learners at all levels—from K-12 to higher education—develop a deeper understanding[8-12].

The main difference between the first two learning styles lies in the depth of focus: **active learning** emphasizes engagement and participation, while **constructivist learning** focuses on understanding and meaning making through exploration. Interactive sims are the intersection of these two approaches which can complement each other, creating a rich learning environment.

Inquiry-based and constructive learning styles can feel synonymous. **Inquiry-based learning** often aligns with constructivist principles because it involves active participation and student driven exploration, both of which are core to constructivism. However, constructivist learning is broader and encompasses all types of active, experience-based learning, not just those focused on inquiry. In an inquiry-based approach, students might explore why chemical reactions produce heat by designing and conducting experiments. In a constructivist approach, students use their observations from the inquiry (lectures can be a source) to build an understanding of concepts like energy transfer, connecting these ideas to prior knowledge.[13,14]

Inquiry-based learning emphasizes on the <u>process</u> of exploration and questioning, while constructivist learning focuses on the <u>outcomes</u> of building knowledge through experiences. The two approaches often complement each other and are frequently used together in student centered classrooms to foster both curiosity and deep understanding. In our work, since these tools are integrated to promote the learning outcome, it feels more appropriate to use the constructive learning tag. In a laboratory setting, inquiry-based learning is the prominent modal. This means virtual immersive laboratory simulations are heavily focused on both of these learning styles.

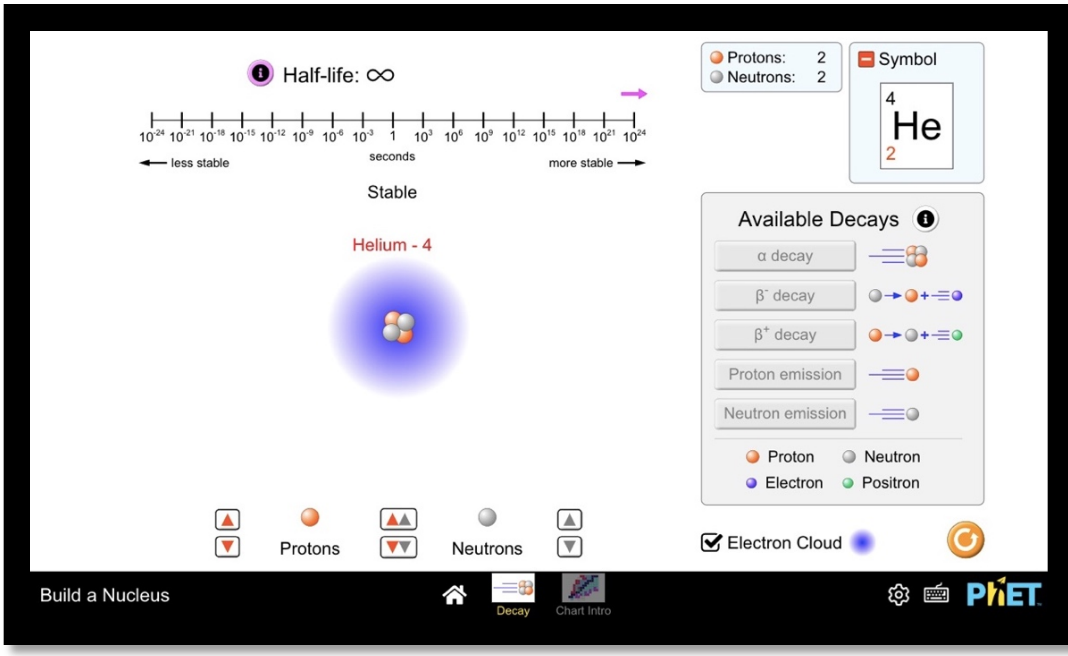

Figure 1 – Browser-based PhET Simulation: Build a Nucleus. User can alter the number of subatomic particles to create different elements and isotopes. Simulation also offers advance topics such as half-life and decays. Simulation by PhET Interactive Simulations, University of Colorado Boulder, licensed under [CC-BY-4.0](https://phet.colorado.edu) (https://phet.colorado.edu)

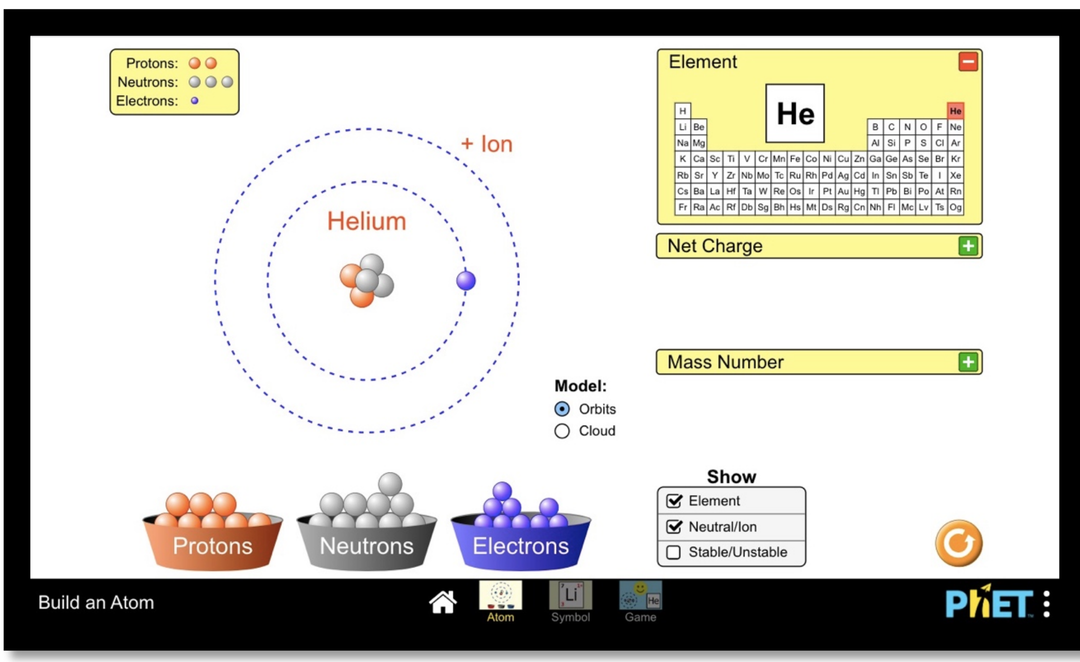

Figure 2 – Browser-based PhET Simulation: Build an atom. User can alter the number of subatomic particles to create different elements, isotopes, and ions and match it to their location on the periodic table. The simulation offers insight into mass number, net charge orbits, and stability. Simulation by PhET Interactive Simulations, University of Colorado Boulder, licensed under CC-BY-4.0 (https://phet.colorado.edu)

Differentiated learning tailors the instruction to meet the diverse needs, interests, and abilities of individual students. It ensures that learners work on tasks appropriate to their skill levels and receive the support they need to succeed.[15] For example, students in the same class may explore the same topic using varying materials or approaches based on their readiness and learning styles. This is usually undervalued in introductory course that often host a larger student attendance in its lecture halls. Smaller recitations are usually offered to address this need. Differentiated constructivist active learning offers a powerful synergy by addressing individual learning needs while fostering active engagement and critical thinking. It ensures that all students, regardless of their skill levels, are appropriately challenged and supported in their journey to construct meaningful knowledge. This combined approach not only deepens understanding but also creates an inclusive, equitable classroom environment where every student can thrive. By blending differentiation with inquiry, educators empower students to take ownership of their learning and succeed at their own pace which is an essential skill to teach students early on in STEM education, where diverse learners must grasp abstract and complex concepts.

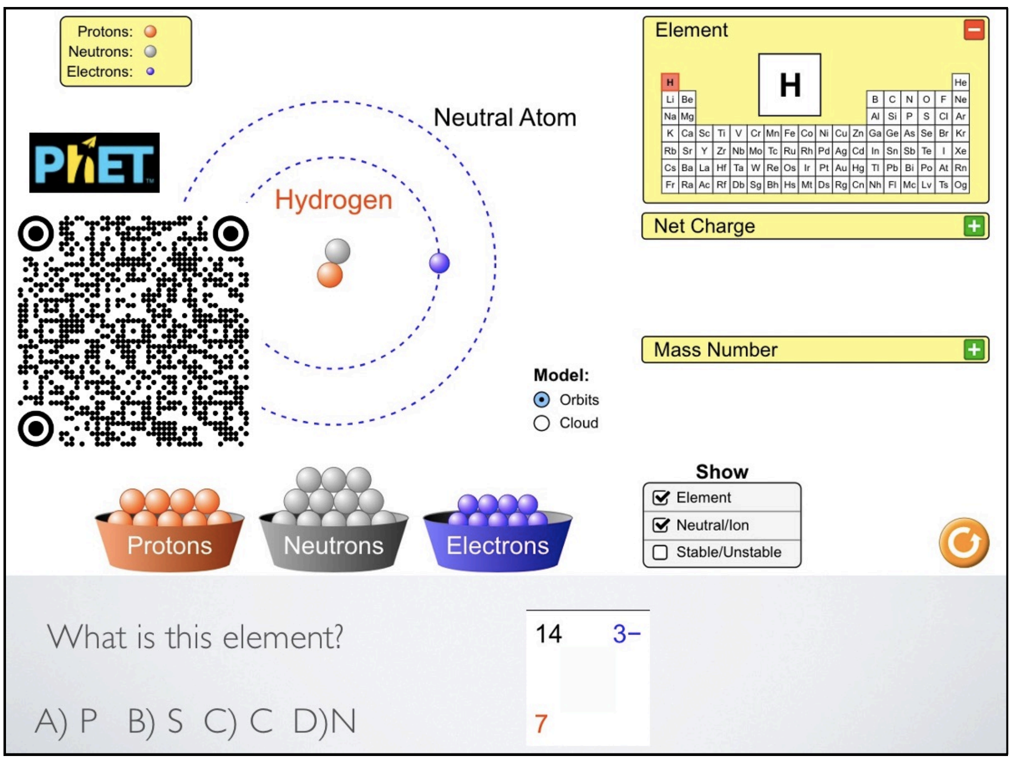

Figure 3 – Clicker projected in class accompanying the simulation shown in Figure 2. Students can use the embedded hyperlink on PhET logo or use their phone camera to scan the QR code to access the simulation and answer the clicker. Simulation by PhET Interactive Simulations, University of Colorado Boulder, licensed under CC-BY-4.0 (https://phet.colorado.edu)

PhET sims are highly relevant in engineering education due to their ability to visualize and simplify complex, abstract concepts that are often challenging for students to grasp. Most engineering disciplines frequently involve topics that are heavily material-science-based at micro-scale, which require a deep understanding of interrelated variables and processes. PhET sims provide a dynamic, interactive environment where students can experiment with these concepts in real-time, adjusting parameters and observing outcomes, thereby bridging the gap between theoretical knowledge and practical understanding.

The gap this study addresses lies in the limited application of PhET sims within engineering education, particularly in introductory engineering courses. While these tools have been extensively studied and proven effective in K-12 education and science-based higher education courses, there is a lack of research on their integration into engineering-specific curricula. By incorporating PhET simulations into clicker-based questions, this study explores their potential to enhance engagement and understanding in a context where traditional teaching methods may fail to capture students' interest or convey the depth of the material. This work fills a critical gap by extending the use of PhET simulations into an engineering framework, providing new insights into how interactive tools can improve both learning outcomes and classroom dynamics.

Research Objectives

The primary goal of this study is to investigate the integration of PhET simulations with clicker-based activities in introductory engineering courses. By combining the interactive visualization capabilities of PhET with the "formative active engagement" provided by clickers, the study aims to evaluate the effectiveness of this approach in enhancing student engagement and learning.

Key metrics for evaluation include:

- **Attendance:** Measuring how many students attend, attend each class to assess engagement.
- **Participation:** Measuring the percentage of students answering each question to assess how actively students engage with the material during sessions.
- **Response times:** Measuring the time it takes to answer each type of question to assess engagement (confidence mode).
- **Accuracy of responses:** Measuring whether the answers to each type of question are correct or not to gauge effective learning.
- **Performance:** Measuring the overall accuracy of responses to each type of question
- **Overall student satisfaction:** Gathering qualitative feedback to understand how students perceive the learning experience and gain an insight into student perspective.

Methodology

Course Overview:

The study focuses on **General Chemistry for Engineers I (CHEN 1201)**, a foundational course designed to meet the general chemistry requirements for engineering students at University of Colorado Boulder during three semesters: spring 2022, 2023, and 2024. This course introduces students to fundamental concepts in chemistry, such as atomic structure, stoichiometry, chemical bonding, thermochemistry, and phase equilibria, with an emphasis on problem-solving and the application of chemical principles in engineering contexts. The course format is lecture-only, and it employs a flipped classroom model, requiring students to complete pre-class readings and screencasts while in-class time is devoted to conceptual discussions and problem-solving activities. Additionally, multiple weekly TA-led recitation sessions are held to provide an additional learning opportunity for a smaller class size. Students in this course are primarily first year engineering students, with a small proportion of sophomores and upperclassmen. Students represent various engineering disciplines, making the cohort diverse in terms of academic and professional interests. Class size is usually 80 to 110 students and recitations are 10-20 students per section. Clickers are only conducted during the lectures. Department enforced prerequisites: High school Algebra, one year of high school Chemistry or CHEM 1021 (minimum grade C-). Restricted to College of Engineering undergraduates.

Technology Use:
The course incorporates clicker-based quizzes, which count for 10% of the overall grade. Some students use physical clicker devices, though the iClicker Student mobile app is also supported and preferred method of delivery. This app expands functionality beyond multiple-choice questions, allowing for more interactive question types such as short answer, numeric, and target. Students who prefer not to use clickers may opt out voluntarily, with their clicker grade being reallocated to the final exam. This policy accommodates those who might find clickers disruptive to their learning. All students enrolled in the course are included in the study except those who opted out. All students are being onboarded during the first few lectures on using different technological tools to ensure proficiency. Students usually have no issue accessing the sims and answering the clicker questions. There are several other teaching tools such as augmented reality modules that are used during the lectures which further enhances tech-proficiency. To reiterate, not every simulation is posted as a clicker and some are utilized for instructional purposes only. There are a few non-PhET sims that are used in class due to lack of sim availability for all the topics.

Class Environment:
The flipped classroom model emphasizes active engagement and participation. Lecture time is structured to involve problem-solving and interactive questioning, which complements the integration of tools like clickers and simulations to enhance understanding of complex engineering concepts.

Clicker Question Formats:
There found to be an optimal 3-clicker limit per 50-minute lecture sessions based on student feedback from spring 2022 semester. Therefore springs 23 and 24 semesters abided by this rule. All clicker questions are posted in advance as part of the blank slide-deck that is accessible 7-10 days prior to the lecture time. Students are clearly instructed before and during the clickers on each problem. The clicker duration depends on the class response time. It usually varies from 60 to 180 seconds with a few outliers. A screenshot of the instructor screen is sent to the clicker page of all students simultaneously to the screen projection in the lecture hall. The class is always given a 30-second warning before the end of each clicker. The warning is announced when 85% of the online users have submitted their answer. This value is determined based on an earlier investigation of clicker response rate and where it starts to plateau. Students are allowed to discuss their thinking with nearby colleagues resembling a group discussion. This also promotes interpersonal relationships between students who share their thoughts with their group which in return could promote attendance as a group activity. There are three general categorizations of clicker questions:

- **Traditional Conceptual Questions (TC):** No simulation use. These are standard clicker questions based on course material that do not involve simulations or any external tools. An example is shown in Figure 4.

- **PhET Instructed Clickers (PIC):** The response does not require the use of simulation by students. Students are mainly observing the simulation while it is being demonstrated and later answer a relevant clicker question. An example is shown in Figures 5 through 7.

- **PhET Interactive Questions (PhC):** The response requires the use of simulation by students. Students are expected to manipulate the variables and analyze specific outcomes. Examples were shown in Figures 2 and 3.

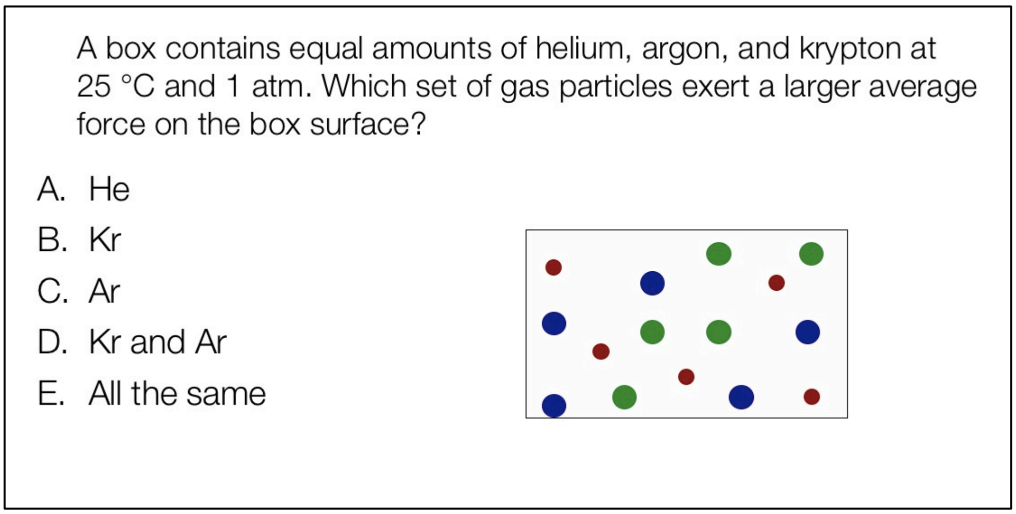

Figure 4 – (TC) Method: The clicker was projected in class on the topic of effusion. There was no simulation used.

For both PhC and PIC, students can access the sims using the embedded link on the slide deck or scanning a QR code projected on the screen. Once the simulation is introduced, the instructor runs it on their projected screen to cover every tunable parameter and sim's capabilities. This demonstration usually takes 2-5 minutes. For PhC, the clicker is then projected on a separate screen while simultaneously being posted on student clicker apps. For PIC, simulation is demonstrated in a similar manner however it is utilized mostly as an instruction tool for a specific topic. Later, clickers on the same specific topic is posted separately which does not necessarily require the use of the simulations.

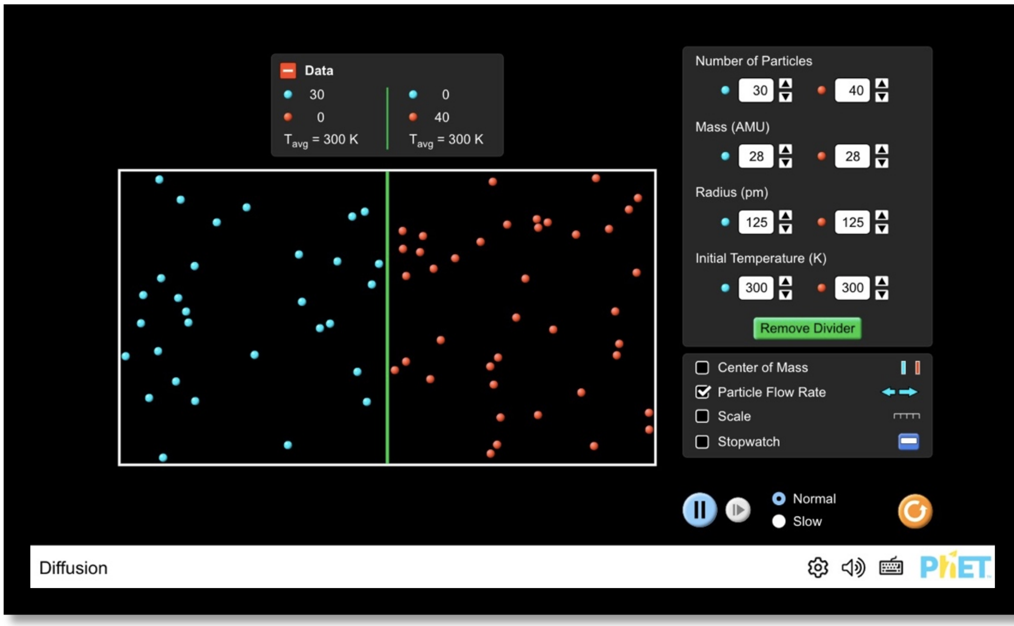

Figure 5 – (PIC) method: Simulation projected in class on the topic of diffusion. Students can use the embedded hyperlink on PhET logo or use their phone camera to scan the QR code to access the simulation and answer the clicker. Instructor demonstrates the effect of mass, particle numbers, atomic radii, and initial temperature by setting these variables and removing the barrier which is shown in Figure 6. Instructor resets the sim a few times to demonstrates the effect of each variable. Simulation by PhET Interactive Simulations, University of Colorado Boulder, licensed under CC-BY-4.0 (https://phet.colorado.edu)

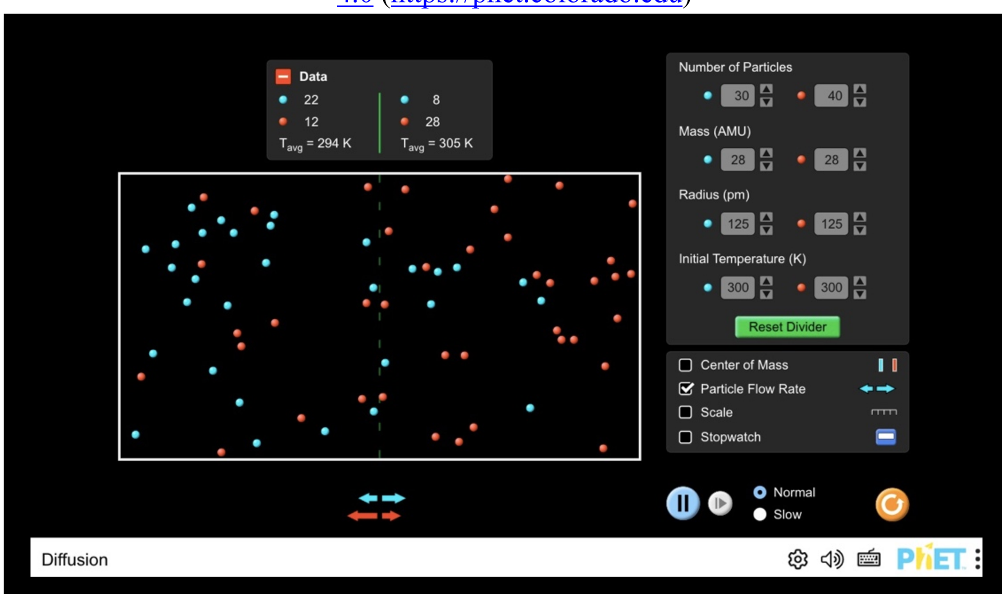

Figure 6 – (PIC) method: Simulation projected in class on the topic of diffusion. The barrier is removed and several outcomes such as particle flowrate, center of mass, and particle numbers can be observed. Simulation by PhET Interactive Simulations, University of Colorado Boulder, licensed under CC-BY-4.0 (https://phet.colorado.edu)

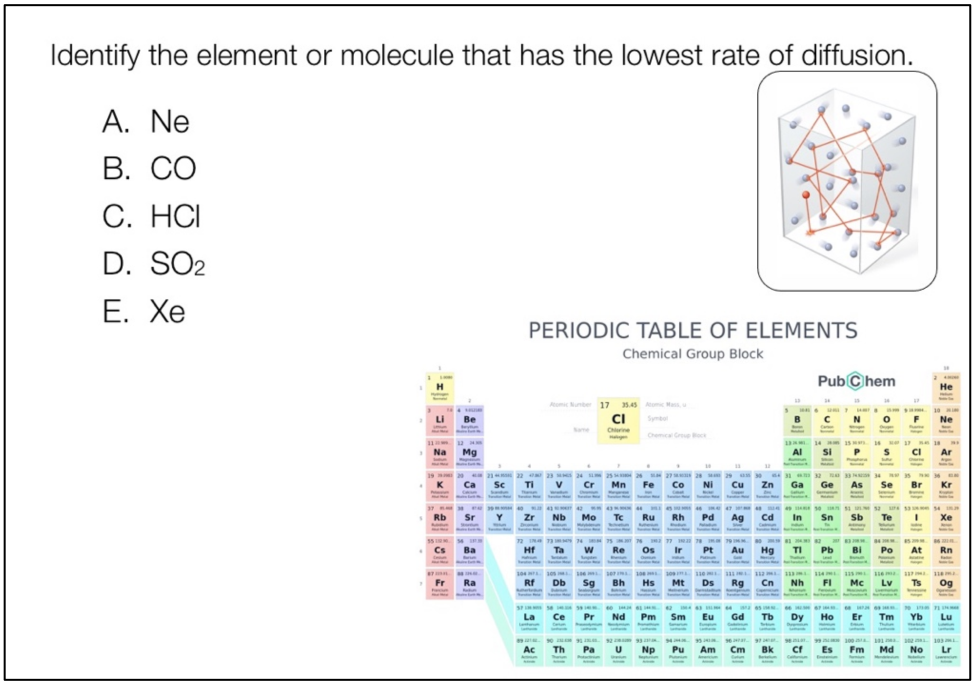

Figure 7 – (PIC) Method: Clicker projected in class on the topic of diffusion. Diffusion sim was utilized to demonstrate the effect of atomic mass.

Data Collection

Key metrics were mostly collected by the iClicker cloud app. The instructor runs the clickers in real time and later grades the class response. The IClicker instructor portal collects raw grades for each clicker question as well as class average and user participation/attendance. The instructor times each clicker question's duration. As it takes a long time to collect all the responses, the clicker duration is defined by when the instructor ends the clicker which is 30 seconds after 85% of active users have responded.

Results from spring 2022 semester (22) and spring 2023 (23) semesters are both based on TC questions only. For these semesters, no simulation was introduced. The reason we have these semesters separately is to show the difference even between the semesters that supposedly have identical clicker set up. It is impossible to obtain similar trends as each cohort is going through different events during their semester. For spring 2024 semester (24) all modalities including TC, PIC, and PhC are utilized and therefore it is labeled as the mixed clicker session/semester. All data excludes students who were absent for more than 85% of the semester which captures the students who opted out voluntarily or dropped out of the course. A small fraction of students (less than 5%) attended less than 50% of lectures but did not drop out of the course nor opt out of clickers. They are included in this analysis. Out of the students who voluntarily opted out of using the clicker, 23% never connected their clickers, 47% missed almost half of the lectures and 30% were not happy with their performance. Roughly 20% of each cohort missed more than 90% of the clickers indicating that not all students like to use clickers. Performance is calculated assigning one point per clicker posted. Every correct answer counts as one and an incorrect answer is zero. Occasionally partial credit is applied for problems that requires multiple steps and results in an incorrect answer because of an error in one of the steps. Since there are higher number of clickers posted in some years, clicker participation and performance results are shown separately.

Results

Figure 8 shows the attendance trends for the the three different cohorts. Semesters 22 and 23 were only answering TC questions, semester 24 was answering a combination of TC, PIC, and PhC. The first observation is the gradual decline of attendance, as the semester progresses. It is also clear that student attendance fluctuates in a cyclic manner mostly due to where in the week the lecture is held. The start (Mondays) and the end (Fridays) of the week in general have a higher attendance rate compared to midweek (Wednesday) sessions. Mixed clicker semester (24) has a generally higher average attendance rate of 86.2% compared to (22) and (23) semesters at 79.3% and 77.2%, respectively. This clearly points out the superiority of mixed clicker style over traditional clickers. The attendance rate drops in a meaningful way for all three time series after every midterm as labelled on the plot. This is mostly due to the assessment fatigue students are experiencing. The attendance rate recovers the session after. There is also the main trench of the time series at lecture 29 which is the Friday right before the spring break. However, it jumps higher than pre break rates. It is interesting to study the student behavior based on semester-specific events which clearly has a drastic impact on their attendance. The attendance is also less predictable towards the end of semester mostly after midterm 3.

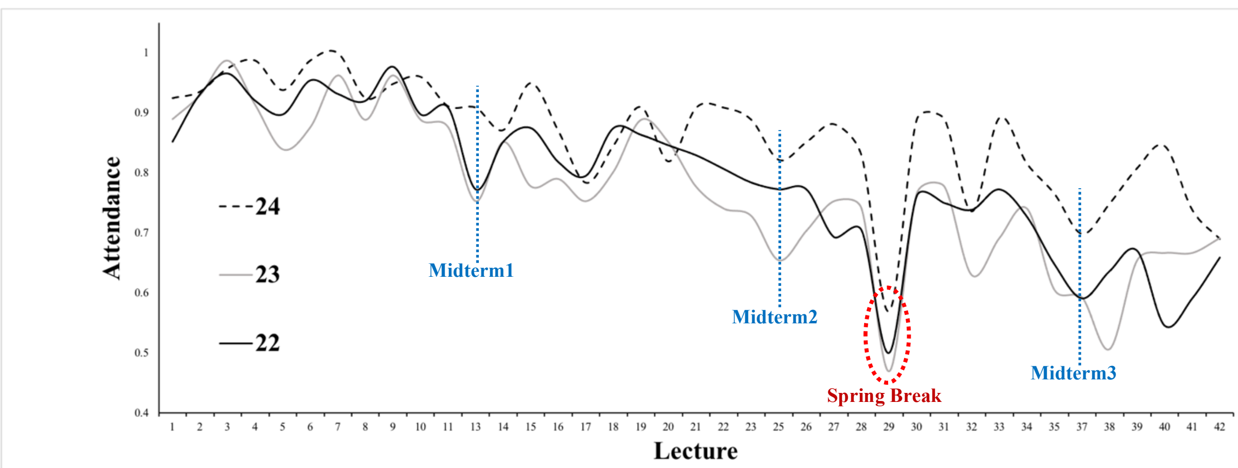

Figure 8 – Attendance over the course of semester. Attendance starts around similar values at the beginning of semester but drifts away between 24 and semesters 22&23.

The average number of clickers posted also dropped with 3.9 clickers per session for (22) followed by 3.05 and 2.11 for (23) and (24), respectively. The change in the clicker numbers and its effect wasn't statistically significant on the performance but a mentioned before was requested by the students to stick to no more than 3-clicker rule. It is also observed that overall performance is highly correlated with the participation trends as shown in Figure 9.

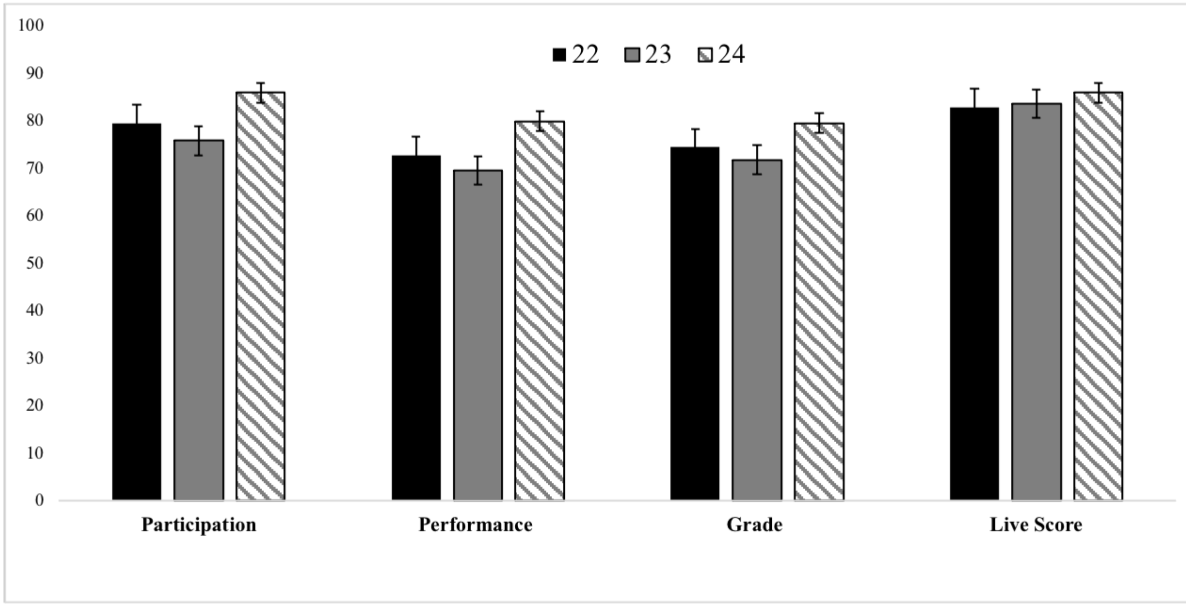

Figure 9 – The average overall participation, overall performance, overall clicker grade, and overall live scores for semester spring 22, 23, and 24. Spring 24 is the only semester with mixed clicker questions. A significant effect was found $p < 0.0001$, $t(39) = 9.33$, df=76.

Participation and attendance grades deviated slightly from one another. The overall grade of each session is calculated based on weighing both participation and performance. Each student received one point if answered more than 50% of the clicker questions in a session. They also received one point per every correct answer. The performance points can be as high as six (for 22), but participation point is maxed at one. This could impose a challenge since the number of clicker questions posted were not always the same. However, there is no evidence of direct correlation between the number of clickers posted and performance. This hypothesis might be flawed since (23) has less clickers posted but ended up scoring lower than (22) with a higher clicker count per session across all grades. Given (22) had the highest clicker average per session and (24) had the lowest, the later received the highest performance points whereas the former is ranking higher than (23). However, the variation in the number of posted clickers could potentially impact the participation grade as a student can face a technical difficulty and booted out of the app for the rest of the lecture. However, in all three semesters, students were required to answer more than one question to obtain the participation grade, therefore it required a higher participation for (24) compared to previous years to receive the participation point. The overall grade is more dependent on the performance as the performance grade can be weighted as high as 85% when six clickers are posted and as low as 50% with only one clicker posted. Therefore, we normalized the results based on equal clickers posted in doing so, the values changed insignificantly.

Next, clicker type effectiveness is shown in Table 1. The comparison is amongst the main question type mentioned earlier to assess the effect of simulations in engagement and learning outcome. It is also important to note that clicker generated performance data counts absents as zeros whereas calculated live score only accounts for the individuals who were present during the session. Clicker grade/performance are significantly higher for PIC and PhC, however, it is crucial to assess the impact of sims rather than their holistic effect. Therefore, live score results were deemed to be more appropriate. As a result, the score gap shrinks between sim-based and TC questions. The live score average for clickers instructed questions are the highest. This could provide a proof that students like to use the simulations for understanding but they do not like it as much when it becomes an assessment tool.

Table 1 – The average live score based on the clicker types. Scores out of 100. A significant effect was found $p < 0.0001$.

Clicker type	**TC**	**PhC**	**PIC**
Live score	84.6 ± 10	85.5 ± 7.9	87.1 ± 7.4

Results in Table 2 show that the live scores are pretty similar when TC-only and mixed clickers are posted which is in contrast with the clicker grade. The clicker grade is significantly higher for mixed clicker group. This suggests that sims are very effective in terms of enhancing the attendance and participation grades but still accounts for the overall performance of students.

Table 2 – Comparing the live score and clicker grades for TC-only and mixed clickers. Live score only accounts for the performance of present students whereas clicker grade is based on all students. Scores out of 100. A significant effect was found $p < 0.0001$.

Semester	**(22)**	**(23)**	**(24)**
Live Score	83.7 ± 11	83.5 ± 8.4	85.2 ± 9.4
Clicker grade	74.1 ± 10	71 ± 7.3	81.8 ± 7.6

There wasn't a strong evidence suggesting the effectiveness of sim-based questions in new topics compared to review topics and regardless of the nature of the content, both review and new material scored pretty similar grades when were taught utilizing sims. As shown in Table 3, live score is not different for both of these categories.

Table 3 – Live scores for sim-based questions for new topics vs review topics. Scores out of 100. A significant effect was found $p < 0.0001$.

Review Topics	New Topics
83.8 ± 7.5	85.8 ± 7.1

One of the key findings was the relationship between the average response time to clicker questions. As mentioned, all clicker questions were explained thoroughly. They were also posted before every lecture to be at students' disposal. The response time was calculated based on the time it takes for 85% of the attending to respond plus 30 seconds. For PhC, the exact question was not always posted since it could change based on the lecture flow. However, sim-based clickers outperformed the TC-questions. PhC showed to have a quicker turn around even compared to PIC. However, simulations might have a negative effect on TC-based questions as it takes longer for students to answer traditional clickers in the mixed clicker semester. This could be due to the less attractive nature of TC clickers compared to sims that offer a dynamic interface and therefore encourages students to engage with it right away, whereas for the TC clickers, student feels the pressure of assessment right away. This is not measured but has been voiced by many students to the instructor.

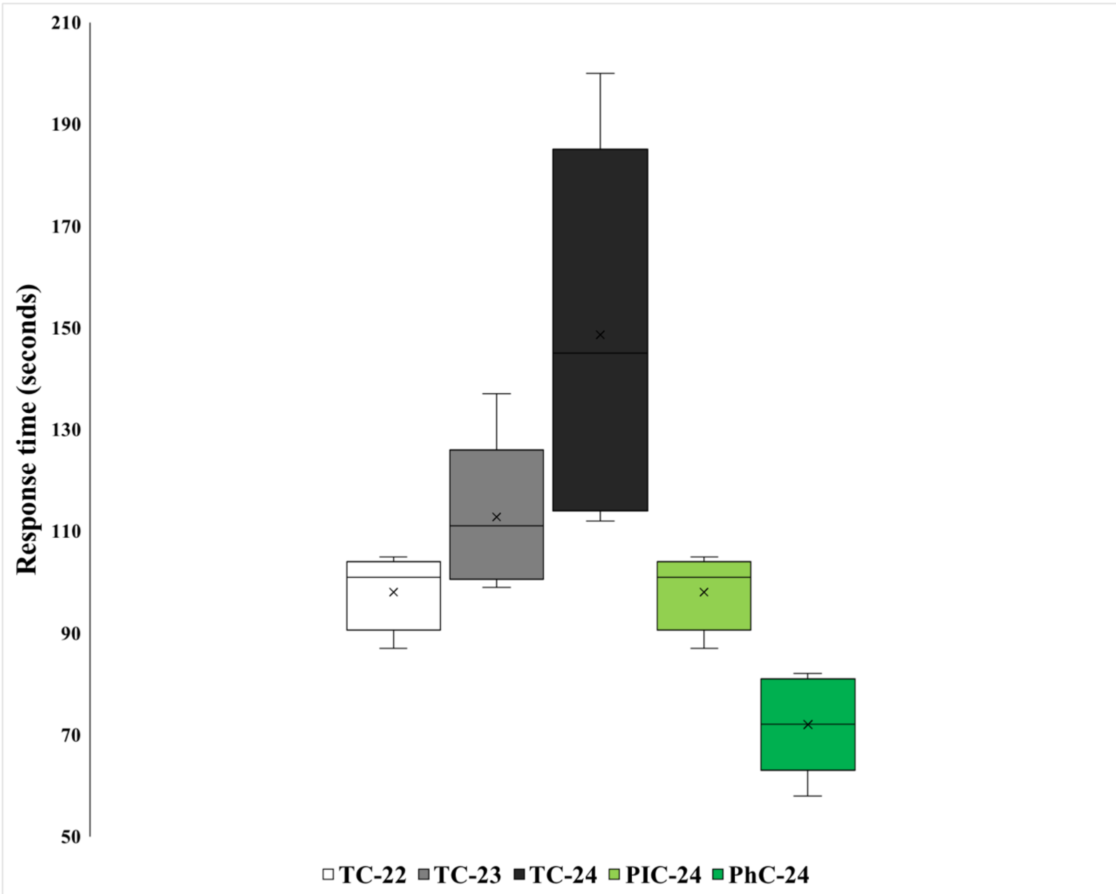

Figure 10 – The average response time for clicker questions. Response time is separated based on clicker and semester. Semesters 22 and 23 only have TC questions. Semester 24 has all three different types of the questions. A significant effect was found $p < 0.0001$.

Discussion

Attendance average was higher for mixed clicker semester compared to the TC-only semesters. This suggests the effectiveness of sim-based clickers in student retention. The cyclic pattern was also another interesting finding which was unexpected. Students cited being fresh at the beginning of the week and motivated to do well before the weekend on Fridays as their main reasons for their higher attendance compared to mid-week sessions. One overarching theme was the gradual decrease in all quantitative measures across the board which aligns with the rest of the course work. It is challenging to keep the student engagement rate as high as the start of the semester, but the mixed clicker model was successful in lowering the drop rate for 80% of the semester. The lack of sims for the topics that constituted the final 20% of the semester may have resulted in a higher drop rate. Potentially this can change if more sims are utilized. Similar drop and rise trends for major semester events such as midterms and breaks were also observed, which points out the necessity for planning for successful student engagement. It is also observed that, if there is no sim, the attendance trends are identical, however mixed questions seem to disrupt these patterns, attendance drops are slower and climbs are faster, always a desired effect. Simulations are very effective in terms of bouncing back from the attendance drops specifically shown after midterm 2 compared to all the other exams. It is worth mentioning that there is only 17 hours between their exam held the night before and clicker session on the next day. This can potentially mean that simulations could bring back students after mind tiring exercises on those low scoring/low attending sessions more notably for overcoming the spring break effect if it is used as a play tool.

Figure 9 illustrates that mixed clickers increase participation, performance and grade, but there is not enough evidence to claim that sim-based questions are better in regard to the learning outcome. This could be due to the fact that most students are using their phone to engage with both the sim and also the clicker portal, therefore some sort of cyber-sickness could be happening. This is also supported by the evidence that PIC live scores are higher than PhC, pointing out that tool is more effective to be used for constructing an understanding rather than an assessment tool which takes the joy out of it. A break from “boring” slide decks is perceived way better than answering another test. When polled, 80% of the students showed their preference for the use of sims compared to only 35% interested in TC clickers. If the performance/clicker grade was determined to be the metric, it could have fully supported the superiority of sim-based questions over traditional clicker questions. The difference between the live score grade and performance grade is smaller for mixed clickers which is another indication to how students exposed to this style are more likely to attend more sessions.

The response time was a major finding of this study shown on Figure 10. Student eagerness and excitement can be linked inversely to their response time. Students suggested that their longer response time for TC questions are due to the fact that TC questions are more similar to the exam style problems and therefore they are reluctant to submit their answers right away. Both the response time data and end of semester performance scores, also suggests that, once a cohort is exposed to the dynamic nature of sims, they no longer perform as well on TC-based clickers. The response time for 22 was similar to PIC-24. This could also mean that when several question styles are posted students can feel overwhelmed and develop a preference. This preference is clearly weighing more towards sims which inherently are more interesting.

Conclusion

The integration of PhET simulations into clicker-based activities in General Chemistry for Engineers I has shown to enhance student attendance, participation, and overall grades compared to semesters using only traditional clicker (TC) questions. Mixed-clicker semesters (combining TC, PhET Interactive Clickers (PhC), and PhET Instructed Clickers (PIC)) showed higher attendance rates and better engagement trends, with simulations particularly effective in mitigating attendance drops after midterms and maintaining student focus. Response time data revealed that students engage more quickly with simulation-based questions, highlighting their excitement and interest. However, the study found no conclusive evidence that simulations alone provide better learning outcomes compared to traditional clickers. Instead, the combination of traditional and simulation-based methods appears to foster the best overall results. Interestingly, while simulations are engaging, their overuse may decrease interest in TC-based questions later in the semester, suggesting the need for balanced integration.

Future Work:

1. **Mixed-Reality Modules:**
   Future studies will explore the use of mixed-reality (MR) tools, such as augmented reality (AR) and virtual reality (VR), to compare their effectiveness on student. These tools may offer deeper engagement with complex topics like intermolecular forces, which are critical in advanced chemical engineering courses.
2. **Topic-Specific Analysis:**
   To better understand the impact of simulations on specific content, we will analyze homework and exam scores for topics initially introduced using simulations. This will help identify whether simulations lead to better long-term understanding of particular concepts.
3. **User Engagement Data:**
   Collaboration with PhET/io to access detailed user engagement data could shed light on whether students revisit simulations outside of class, or how they engage with the sims and how this impacts their learning outcomes. This additional data could also help in identifying trends related to cyber sickness or app usability.
4. **Low-Engagement Sessions:**
   Simulations could be strategically deployed during low-attendance or low-performance sessions to counteract the effects of major semester events, such as midterms or breaks. The success of simulations in boosting attendance after midterm 2 demonstrates their potential in such scenarios.
5. **Immersive Evaluations:**
   Simulation-based midterm evaluations could provide new ways to assess student understanding, though implementation challenges must be addressed.

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