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Abstract

A positive physics identity is crucial for women and minorities who are underrepresented in the field of physics. Pedagogical methods that focus heavily on math rather than concepts present a deterrent to many students in physics courses. This research aimed to determine how a 'gamified' physics curriculum with immediate feedback affects students' perception of their ability to master physics as a discipline. Furthermore, the study aimed to investigate how an online algebra-based physics curriculum, which provides students with multiple levels of mastery in an interactive and responsive format, affects students' physics identity and academic achievement. Survey data were analyzed via ANOVA and/or discriminant analysis to determine shifts in participants' attitudes about physics as the school year progressed. While the students' self-assessed physics ability improved in the classroom, their assessment of their ability to do physics on a professional level decreased. This coincided with a decline in their interest in physics. In addition, the students did not prefer one content delivery method over another. These data suggest that even as students' perceived ability in physics increased, the improvement in ability was confined to their current class.

Introduction

It is common to hear physics described as an inaccessible and difficult subject. This is especially true for historically underrepresented groups in the STEM field (Kelly, 2013; Krakehl & Kelly, 2021; Quichocho et al., 2020). Educators and researchers alike have been asking how to eliminate the marginalization of students from diverse populations who could contribute to and advance the STEM industry in the United States (Czujko et al., 2008; Hazari et al., 2017; Merner & Tyler, 2019; Porter, 2025). Multiple studies have revealed that urban youth, particularly those underrepresented in STEM fields, have inequitable access to and participation in physics courses (Kelly, 2013; Hazari et al., 2017; Krakehl & Kelly, 2021). Additionally, a strong 'physics identity' has been identified as a marker for success in physics and physics-related careers (Bottomley et al., 2022; Cheng et al., 2019; Hazari et al., 2015). To increase motivation and confidence in students, there is increasing interest in gamification, which can positively affect students' perceptions of themselves in physics (Beltoazar-Clemente & Díaz-Vega, 2024; Gaurina et al., 2025).

Literature Review

Limited participation in STEM fields by women and historically underrepresented groups is a persistent issue that has been extensively documented (e.g., Czujko et al., 2008; Merner & Tyler, 2019). In 2021, Black students earned 9% and Hispanic students earned 16% of the total number of bachelor's degrees awarded in the US. However, Black and Hispanic students account for 3% and 12% of the total physics bachelor's degrees (National Center for Science and Engineering Statistics (NCSES), 2024; Porter et al., 2024). Merner and Tyler (2019) found that although bachelor's degrees earned by Black students in the United States increased from 2005 to 2015, bachelor's degrees in physics and engineering attained by Black students did not increase at the same pace. The total number of bachelor's degrees in physics increased by 57% from 2005 to 2015 yet the number of physics bachelor's degrees earned by Black students only increased by 4% (Merner & Tyler, 2019). A similar trend exists for engineering degrees. The number of engineering bachelor's degrees increased by 44% from 2005 to 2015 but engineering degrees earned by Black students only increased by 19% (Merner & Tyler, 2019). Similarly, women account for only 25% of the total physics bachelor's degrees (Porter, 2025). Women of color account for an even smaller percentage of physics bachelor's degrees with women of color earning only 181 of the approximately 5000 bachelor's degrees in physics in 2007 (Council, 2013).

The disparity in physics graduates can be reduced in high school as 72% of students graduating with a bachelor's degree in physics credit their high school physics experiences as the reason for their interest in physics (Porter et al., 2024). This finding underscores the significance of high school physics curricula and classroom experiences on future success in physics for all students. Our research aims to determine how a specific pedagogical strategy in high school affects physics identity, which in turn could affect who graduates with a bachelor's degree in physics.

Physics Identity

Research has shown that students need a positive 'physics identity' to have a favorable outlook on physics and careers related to it (Hazari et al., 2010). Physics identity refers to how a student perceives themselves in relation to physics as a discipline and a career (Hazari et al., 2010). This identity is shaped by interest, recognition, and performance (Hazari et al., 2017). A strong and positive physics identity is linked to academic and professional success in physics (Cheng et al., 2019; Hazari et al., 2010; Irving & Sayre, 2016; Quichocho et al., 2020). Students' high school physics experiences, especially when it's their first time taking a physics class, significantly influence physics identity (Close et al., 2016). Both explicit and implicit recognition by high school physics teachers also positively impact the development of a physics identity (Wang, 2018). Low physics identities are thought to be linked with lower representation of certain demographics in physics-related and engineering fields. A positive physics identity is especially important for women, who are underrepresented in physics (Hazari et al., 2017; National Center for Science and Engineering Statistics (NCSES), 2024). Hispanic and Black workers make up 18.2% and 11% of the workforce, but only 9.5% and 6.8% of the science and engineering workforce, respectively (National Center for Science and Engineering Statistics (NCSES), 2024).Multiple studies have also found that the intersection of race and gender can have compounded effects on physics identity, with Black and Hispanic women showing lower physics identity rates (Hyater-Adams et al., 2018; Krakehl & Kelly, 2021; Quichoco et al., 2020).

According to the NSF, there were fewer women than men in science and engineering jobs in 2021 (National Center for Science and Engineering Statistics (NCSES), 2024)Women often have low levels of strong physics identities (Bottomley et al., 2022; Kalender et al., 2019). Women's physics identities especially benefit from recognition by physics teachers (Kalender et al., 2019). Disparities are seen at the high school level, where a study showed that women only have a 20% and 50% pass rate respectively on the AP Physics 1 and AP Physics 2 exams (Krakehl & Kelly, 2021). Women's physics identities improve with interventions that highlight women's contributions to physics and engineering (Cheng et al., 2019).

Gamification

'Gamification' involves incorporating game-like elements into education or other non-game settings (Amado & Roleda, 2020). Educators and researchers have examined gamification to boost student engagement across various academic fields (Amado & Roleda, 2020; Balci et al., 2022; Beltozar-Clemente & Díaz-Vega, 2024; Gaurina et al., 2025; Richter & Kickmeier-Rust, 2025; Tolentino & Roleda, 2019). Curricula have been designed to include structural gamification elements such as levels, points, progress bars, challenges, feedback, leaderboards, and badges. Research shows that gamification serves as a motivation source for students and helps with the long-term retention of concepts (Beltozar-Clemente & Díaz-Vega, 2024). Furthermore, gamification increases students' confidence in solving difficult problems (Gaurina et al., 2025). Studies have demonstrated that gamification is effective across different age groups and disciplines, making classroom experiences more enjoyable (Gaurina et al., 2025). Although gamification can improve classroom experiences, this improvement is mostly absent in students' quiz performance (Richter & Kickmeier-Rust, 2025). Our review of the research indicates that the impact of any level or type of gamification on physics identity has not yet been published (Balci et al., 2022; Richter & Kickmeier-Rust, 2025). This study seeks to add to the existing research on physics identity and gamification in physics.

Research Question

Our research examined how a non-traditional physics curriculum that includes game elements affects the development of physics identities among high school students in an urban setting. We hypothesized that if students found the medium they used to learn physics concepts and mathematical tools more engaging, more students would believe they could master physics as a discipline, leading them to develop a stronger physics identity. We targeted a group of students attending an urban high school where the majority of students are Black and Hispanic.

Methods

Participants

All participants (N=24) were students in a physics course taught by the first author at a magnet public high school in an urban area. The students at this school are 40.4% male, 59.6% female, 45.4% Black, 50% Hispanic, 0.7%

White, and 1.1% two or more races. Additionally, 91.5% of students at the school are socioeconomically disadvantaged, 2.5% are English learners, 4.7% have documented disabilities, and 0.9% are foster youth (*School Accountability Report Card*, n.d.). The students in this study were enrolled in either Honors Physics or AP Physics 1. The participants in this study were 46% female, 54% male, 17% Black, 8% two or more races, and 75% Hispanic.

Data Collection

For this study, the first author designed a five-point Likert scale survey entitled 'Physics and You' to assess how the Honors Physics and AP Physics 1 students felt about themselves in relation to physics and physics as a discipline (see Table 1). Students also answered questions about their perceived ability to do physics. Students took this survey three weeks before the end of the fall semester and again three weeks before the end of the second semester of their physics course.

Table 1. Likert Statement Groups

Topic	Statement
Physics Interest	I like studying physics.
	I want to become a physicist.
	I want to major in a discipline that requires a lot of physics.
	Physics is exciting.
Physics Person	I see myself as a 'physics person'.
	Others see me as a 'physics person'.
	Physicists look like me.
Professional Physics Ability	I can be a physicist if I want to.
	Physics is too hard for me.
	I can be successful in higher-level college physics courses.
	I have a deep understanding of physics.
Physics Ability	I can design and execute my own physics experiment.
	I have the skills to tackle a physics problem.
Content Delivery Method	Reading a physics textbook makes me feel more like a physicist.
	Answering questions online makes me feel more like a physicist.

Classroom Activities

We used a 'gamified' computer-based physics curriculum titled "Positive Physics". This curriculum combines inquiry and psychology to improve student engagement and agency in this challenging science subject (Positive Physics, n.d.). The curriculum groups physics concepts into units similar to traditional textbooks; however, students are given a series of problems that offer immediate feedback as they learn. In addition, the curriculum offers multiple difficulty levels. Each unit starts with a review, followed by a digital, interactive inquiry activity. The review revisits previously learned physics concepts and problems to prevent the loss of knowledge from earlier units. The inquiry activity requires students to interact with phenomena to understand and draw conclusions before introducing concepts to students. After the inquiry, there are a series of lessons that increase in difficulty. Each lesson begins with an instructional video and notes, then continues with interactive questions that give students immediate feedback. Correct answers are marked in green, and incorrect answers are marked in red. There are also lessons aimed at strengthening the math skills needed to understand the physics concepts in the unit. As students work through questions, they receive immediate feedback, with parts of questions turning green or red based on correctness. Getting a question wrong doesn't stop them from progressing through the unit, and they can try a question repeatedly until all parts turn green. Each question features randomized numbers so students can help each other understand the concepts but cannot copy answers. This 'gamified' curriculum, where students collaborate to 'beat levels,' and has unlimited attempts with instant feedback, enables students and teachers to constantly monitor understanding and recognize when a student is ready to 'level up' to a more advanced aspect of a concept.

Students were assigned units to complete for classwork and homework. Approximately 40% of the units were classwork and 60% were homework. The first author would guide students through representative problems in class, and students would then solve these problems in small groups. The first author demonstrated how to solve problems without solving the students' problems, as each question had randomized numbers. Additionally, the first author created instructional videos that show how to solve more complex problems. These activities were part of holistic instruction that included laboratory investigations, engineering projects, and whole-class lessons. These pedagogical methods were used throughout the school year, before and after the pre-survey and before the post-survey.

Results and Discussion

We analyzed the coded data from the pre- and post-surveys and found statistically significant differences. Due to this study's small sample size, we grouped similar questions for analysis (see Figure 1). We used the statistical software IBM SPSS Statistics to perform paired t-tests on their pre- and post-surveys. A Wilcoxon signed-rank test was used to identify any statistically significant changes in students' responses to the Likert scale question groups.

Students were initially asked Likert scale style questions about their feelings towards physics as a discipline during the fall semester. The median scores for questions pertaining to physics interest and professional physics ability were slightly above the neutral score of 3.625 and 3.375, respectively ($N=24$). Conversely, the median score for the physics person category was slightly below the neutral score at 2.667 ($N=24$). Physics ability and content delivery method had neutral median scores of 3 ($N=24$).

After the implementation of the gamified curriculum, the median scores for the student responses in the physics person and physics ability categories increased at the end of the second semester. The median score for the physics person category increased from 2.667 to 3 and the median score for the physics ability increased from 3 to 3.5. The increase in the physics ability category was statistically significant ($p < 0.05$). The median scores for both the physics interest and professional physics ability categories decreased after the implementation of the gamified curriculum. Students' physics interest median scores decreased from 3.625 to 3.25 and the median scores for professional physics ability decreased from 3.375 to 3.125. The decrease in students' interest in physics was statistically significant ($p < 0.01$). The students' thoughts about the content delivery remained neutral with a median score of 3 before and after the implementation of the gamified curriculum.

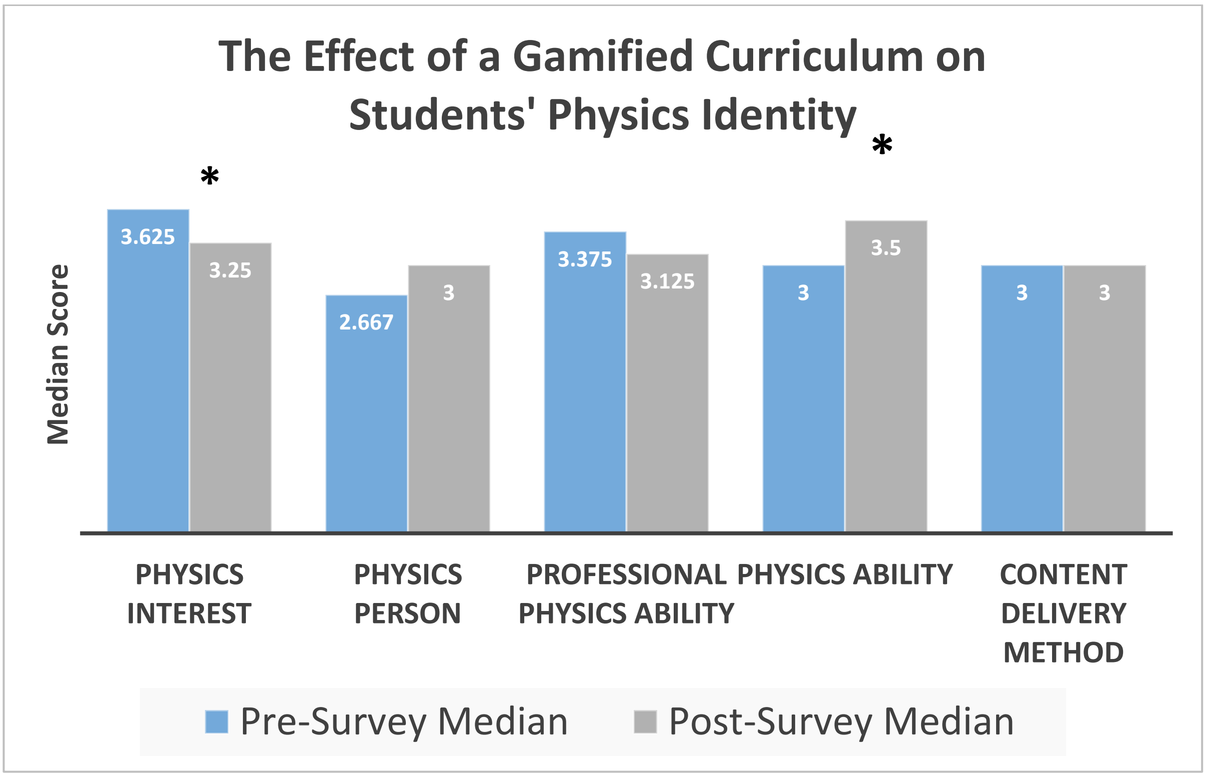

Figure 1. The Effects of a Gamified Curriculum on Students' Physics Identity

Note. Median scores are shown for pre-survey and post-survey question groups.

*indicates a p-value of <0.05.

Our data reveal that the gamified curriculum was correlated with an increase in students' confidence in solving physics problems and conducting laboratory experiments. However, the confidence that the students had in the physics classroom did not extend beyond it to physics careers. Students' interest in physics as a professional discipline decreased. Additionally, we did not find a statistically significant change in students' perceived 'physics identity'. However, we did observe an increase that may be replicated with further study and a larger study population. This suggests that gamification is correlated with an increase in classroom confidence and may influence the development of a physics identity.

Impact of Gamification on Classroom Confidence

The implementation of a gamified curriculum had a positive impact on students' confidence in the classroom. After the gamified curriculum was implemented, students became more confident in their ability to tackle the challenges in the physics classroom successfully. This finding is consistent with research on gamified curricula in other courses (Beltoazar-Clemente & Díaz-Vega, 2024; Gaurina et al., 2025). This data suggests that implementing a gamified curriculum can improve students' perception of and performance in high school physics courses. Although the students in this study were honors physics and AP physics students who voluntarily enrolled in the course, many of them were intimidated by the material. They only took it after their counselor suggested it. This could indicate that gamification will also increase confidence in general high school physics classrooms. Further research on gamification should be done in general physics classrooms as well as honors and AP classrooms.

The gamified curriculum boosted students' confidence in their ability to solve physics problems and to design and carry out physics experiments. Designing and conducting experiments demands more critical thinking skills that are not explicitly taught in the gamified curriculum used in this study. This finding suggests that as students' confidence in solving physics problems increases, their confidence in understanding physics concepts also grows. This boost in confidence carries over to other classroom activities, such as designing and implementing experiments. Gamification could be especially beneficial for increasing the pass rate of women of color taking AP physics I and II (Krakehl & Kelly, 2021).

Impact of Gamification on Physics Identity

Our results show that a gamified curriculum resulted in a marginal increase in students' physics identity ratings. However, this increase was not statistically significant. This study should be repeated with a larger sample of students to obtain more conclusive data. However, this preliminary data suggests that gamification in the physics classroom can have a positive effect on the development of a physics identity in high school. The increased confidence that students reported may have influenced the slight increase in physics identity.

Physics identity depends on various factors, such as recognition, mentoring, interest, and utility (Cheng et al., 2019; Close et al., 2016; Hazari et al., 2017; Kalender et al., 2019; Wang, 2018). All students in this study come from historically underrepresented populations in physics and STEM fields. Recognition may play a more significant role in developing a positive physics identity among populations that have been historically underrepresented in physics (Cheng et al., 2019; Hyater-Adams et al., 2019). Additionally, a study has shown that Black physics identity is strongly shaped by ideational resources identified by the critical physics identity framework (Hyater-Adams et al., 2018; Hyater-Adams et al., 2019). Internal positioning within physics is especially crucial for Black physicists, and this may also apply to Black and Hispanic high school students new to physics as a discipline and potential career path. Black and Hispanic students would greatly benefit from feeling a sense of belonging in the field of physics. Further research exploring the impact of extensive interactions with physicists and engineers from similar backgrounds on physics identity development in high school students from historically underrepresented groups would greatly benefit the field.

Impact of Gamification on the Pursuit of Physics Careers

One of the more surprising findings from this study is that students' interest in physics and desire to pursue physics as a career decreased even as their confidence in the physics classroom increased. Students may need more than confidence in the classroom to believe they can succeed as physicists, engineers, or in other physics-related careers. Students may need more experiences that connect physics to their community to relate to the subject and consider it as a potential career path. It's essential to consider that all the students in this study are Black or Hispanic when analyzing the results of this study as these two groups have historically been underrepresented in physics (Merner & Tyler, 2019; Porter et al., 2024). Research indicates that the cultural values of physics need to be interrogated and people with values outside of the historical norms of physics need to be embraced into the physics community (Hyater-Adams et al., 2019). Additionally, students may need to engage with physics mentors they can relate to (Kricorian et al., 2020). Although gamification has been identified as a source of motivation and confidence in the classroom, our research reveals that gamification doesn't inspire students to choose a career on the game subject matter (Beltozar-Clemente & Díaz-Vega, 2024; Gaurina et al., 2025; Hazari et al., 2010).

Some students from the AP Physics course went on to major in physics or engineering in college. However, many of these students had that career path in mind before taking the class. Additionally, these students were highly competitive in the classroom and enjoyed the difficulty of the course concepts, whereas other students would become discouraged by the course's rigor. Our data is consistent with research in other high school physics classrooms where students from historically underrepresented groups struggled (Krakehl & Kelly, 2021). Further research should focus on how to increase the success of students from underrepresented groups in general high school physics and AP Physics.

Limitations of the Study

Given the sample population of this study, it is important to interpret the results within the context of the study's constraints to better understand the study's strengths and weaknesses and identify avenues for future research. The study was conducted with a single class of 24 students. While the small sample allowed for close observation, it limits results. Therefore, the data should be considered preliminary until a similar study is conducted in the same environment or in a comparable environment. Universally used statistical tests that would have identified significant changes with a high level of confidence could not be used to analyze this data. A larger sample would help balance these extremes and provide more stable, generalizable results.

An unconscious emphasis could be placed on the tested curriculum in the classroom given the two roles of teacher and researcher. The teacher's experience with the students in the classroom serves as a lens by which the data is viewed and analyzed. If the teacher perceives a greater physics identity in their students due to their behavior, they may see this change in the data as well. Implementing this research across multiple sections of physics with different instructors would both increase the sample size and minimize bias due to the instructor.

Generalizability

Given this study was conducted in a single, urban high school with a small and demographically specific group of students, generalizability is limited. The participating students were predominantly Latino and African

American, with a mix of low-income and working-class backgrounds. Schools in rural areas, affluent suburban districts, or international contexts may face different challenges and opportunities in implementing similar programs.

Furthermore, the success of the intervention depended in part on reliable student access to computers and the internet in school and at home. Replicating the program in other settings would require consistent internet access for students. This is especially important for students in rural areas or from lowered socioeconomic households.

To strengthen generalizability, future studies should increase the number of students studied, include general, honors, and AP Physics students, include students from a variety of backgrounds, and include a researcher who is not the teacher of the students in the study. While this study offers valuable insights, its results should be regarded as preliminary and best understood as a justification to conduct further research into gamification and physics identity.

Validity

The small sample size of the study could impact its validity. Although statistical analyses of the data were conducted, the interpretation of the data is still bound by the small sample size. Further research must be done to fully define the relationship between gamification and physics identity.

Reliability

Even with strengths, some factors may have affected reliability. The small sample size of 24 students meant that random fluctuations had a greater influence on overall results. In addition, teacher observation, while helpful for adding context, was subjective and could reflect researcher bias. Future studies could strengthen reliability by increasing the number of teachers included in the study and including a researcher who is not an instructor of the course research participants.

Conclusion

We have found that gamification of a physics curriculum positively influences students' perceived physics ability and helps develop a physics identity. However, it does not increase students' perceived professional physics interest or professional physics ability. Yet, gamification does have instructional benefits (Amado & Roleda, 2020; Balci et al., 2022; Beltozar-Clemente & Díaz-Vega, 2024; Gaurina et al., 2025; Richter & Kickmeier-Rust, 2025; Tolentino & Roleda, 2019). Our research suggests that curricula with game elements are a useful initial step to foster a positive connection between physics and students from underrepresented groups. This study offered preliminary findings that would benefit from further research with a larger sample size, which could lead to more definitive results. Additionally, combining open-ended responses with Likert-scale questions would yield more comprehensive data to better understand the factors that contribute to the development of a positive 'physics identity." Gamified curricula should be researched further to determine the role it could play in bridging the disparities in physics degrees awarded to Black, Hispanic and female students (Council, 2013; National Center for Science and Engineering Statistics (NCSES), 2024;). More interventions and innovative curriculum strategies are necessary to strengthen physics identities and promote future professional physics careers in students from these groups.

Recommendations

We recommend that physics curricula used in urban schools with students who are historically underrepresented in STEM include gamified elements to increase student performance and confidence. The interactive and responsive nature of gamification positively benefits these students and with more targeted interventions, it could help increase the participation of these students in physics and physics-related careers.

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