Exploring the Impact of Virtual Reality and Augmented Reality on Enhancing Physical Education and Fitness Engagement Among Adolescents

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Abstract- ***This study explores the impact of Virtual Reality (VR) and Augmented Reality (AR) technologies on enhancing physical education (PE) and fitness engagement among adolescents, addressing the growing need for innovative educational strategies to improve student participation and physical activity levels in the context of modern technology. Over a 12-week experimental period conducted in various secondary schools, a cohort of 200 adolescents (aged 12-16) were randomly assigned to either a VR/AR-enhanced PE program or a traditional PE curriculum, with each group consisting of 100 students. The VR/AR program integrated immersive, gamified experiences such as virtual sports environments and AR-driven interactive fitness challenges, while the traditional program followed standard physical education routines based on physical activities like running, ball games, and gymnastics. Pre- and post-intervention fitness assessments, including aerobic capacity, flexibility, and strength, were performed using standardized tests (e.g., 12-minute run, sit-and-reach test, and push-ups), alongside surveys to measure engagement, motivation, and perceived enjoyment of the PE activities. Data analysis revealed that participants in the VR/AR group exhibited a statistically significant increase in physical activity levels, with a 30% higher average score in aerobic capacity tests compared to the traditional PE group, as well as a 40% increase in student engagement and motivation, as reported through the engagement survey. Additionally, 70% of the students in the VR/AR group reported a greater sense of enjoyment and fun, with 65% indicating they would prefer incorporating more technology-based PE activities into their routine. In contrast, the traditional PE group showed only a 5% increase in fitness scores and a 10% increase in engagement, indicating limited improvement in both physical fitness and motivation. These findings suggest that VR and AR technologies significantly enhance adolescents' engagement, motivation, and fitness outcomes in physical education, potentially offering a novel pathway for improving physical activity adherence in an increasingly sedentary digital age. This research highlights the need for further exploration into the long-term effects of VR/AR on physical education and fitness, particularly regarding sustained motivation and health benefits beyond short-term intervention periods, making a compelling case for future integration of immersive technologies in school PE curricula as of 2024.***

Indexed Terms- ***Virtual Reality (VR), Augmented Reality (AR), Physical Education (PE), Adolescent Engagement, Fitness Motivation, Technological Integration in Education***

I. INTRODUCTION

Participation in PE and fitness activities by adolescents is an essential aspect of overall health, cognitive development, and lifelong fitness, as the World Health Organization (WHO) (2023) has reported that more than 80% of adolescents worldwide fail to achieve the recommended 60 minutes of daily moderate-to-vigorous intensity PA, which in turn places them at risk for excessive weight gain, cardiovascular disease, and mental health problems, yet meanwhile schools continue to encounter declining levels of student motivation and stamina when engaging in traditional PE classes that often emphasise rote instruction and repetitive practice of standardized sports that may not appeal to the spectrum of adolescent interests and needs, thereby necessitating new pedagogical strategies to revitalize PE participation and promote intrinsic motivation (Bailey et al., 2019; WHO, 2023).The recent explosion

in Virtual Reality (VR) and Augmented Reality (AR) technologies in the educational space presents new and promising opportunities to redefine how students interact with learning environments, as VR offers scenarios that fully immerse students in a simulated world that replicates or extends experiences derived from the physical world, while AR overlays digital elements on physical objects in a real world context to create an interactive experience that merges physical and digital worlds, both of which have gained traction as learning tools across disciplines such as science, medicine, and technical training by virtue of their capacity to boost engagement, experiential learning, and the retention of material (Radianti et al., 2020; Akçayır & Akcayır, 2022).Within PE more specifically, VR based programs that include virtual cycling, exergaming, and dance simulations, along with AR-based applications such as digital step-counters that offer real-time feedback, interactive skills drills, and gamified PE modules, have shown promise in boosting enjoyment, motivation, and even effort levels of students (Gao et al., 2020; Martin et al., 2022), yet evidence gaps still exist regarding their empirical effectiveness in outperforming traditional PE modes when it comes to adolescents, as well as their potential for driving sustained fitness and motivational change, and it is this latter issue that constitutes the central research problem of this research, namely that traditional PE techniques are increasingly unable to meet adolescents' motivational and fitness needs in the digital-first era, thus underscoring the need to rigorously investigate how VR and AR can offer fresh opportunities that are aligned with students' technological profiles and psychological expectations. Therefore, the aims of the current research are two-fold: firstly to examine the impact of integrating VR/AR technologies on physical education (PE) engagement, and body fitness within adolescent students, specically exploring motivational properties, participation rates, and quantizable body outcomes such as aerobic capacity, muscular strength, and exibility secondly, to compare the electiveness of VR/AR enhanced PE programs against conventional methods to ascertain whether these emerging technologies exert stronger eects in improving both engagement and body and to provide empirical evidence to justify the application of VR/AR in classroom-based educational activities. The contribution of this study lies in its potential ability to reshape the pedagogy of PE through VR and AR, offering to gamify fitness experiences, to customize activities according to different student preferences, and create a safe, inclusive, and vibrant environment where adolescents are more likely to participate, especially in those who are not very inspired or confident to turn their attention to a sports-based traditional PE programmes (Parong & Mayer, 2021; Djordjevic et al., 2023), and in the context where sedentary and screen dependency has increased as a global health challenge among adolescents at post-pandemic years (UNESCO, 2022), the integration of VR and AR into PE could, paradoxically, harness technology itself to prevent inactivity; positioning immersive and augmented technologies as not competitor but facilitator for physical activity. Based on these orientations, the research questions and hypotheses that drive the current report include: (i) what is the impact of VR and AR technologies on adolescent participation in PE, with the hypothesis that students who experience VR/AR-inflected PE will report higher levels of motivation, enjoyment and willingness to participate than peers in traditional programs; and (ii) does VR and AR-based PE yield superior fitness outcomes as compared to traditional PE, with the hypothesis that objectively measured indicators of physical performance will demonstrate statistically significant improvements in VR/AR groups due to the higher levels of sustained participation and intensity, and collectively, these questions seek to address an urgent gap in current educational practice by providing critical insights into how PE might be reshaped within schools to adapt to the demands of technological advances and the needs of a digitally native adolescent generation as of November 2024 (Akcayir & Akcayir, 2022; OMS, 2023; Djordjevic et al., 2023).

II. LITERATURE REVIEW RELATED TO THE STUDY

For many decades, physical education (PE) and adolescents' engagement in fitness have been recognized as significant contributors to the nurturing of lifelong practices of staying healthy, however motivating young individuals to be active participants in PE classes remains challenging for both educators and researchers who are struggling to engage young people to take an active role in PE, as traditional PE

programs fail to address diverse interests of adolescents, a large proportion of whom are highly disengaged due to lack of enjoyment, perceived low competency, and limited exposure to non-traditional sports and fitness activities (Dale et al., 2021; Wang et al., 2022) since nearly 60% of adolescents claim they are not interested in typical PE routines, which contributes to low levels of physical activity and health risks linked with sedentary practices (WHO, 2023), supporting the demand for alternative methods that could enhance engagement through technology; one of the most promising ways is the application of Virtual Reality (VR) and Augmented Reality (AR) which have revolutionized many areas of education by generating immersive and interactive learning experiences that are more closely related to the interests and cognitive needs of today's students (Hwang et al., 2022; Radianti et al., 2020) as such technologies offer new opportunities for young students to interact with educational content through simulated environments or real-time digital enhancements of the natural world, thus providing new avenues for rejuvenating PE programs. Specifically, VR and AR technologies in PE have gained traction for their potential to physically engage students in a way that brings an edge of entertainment to education by using the same gaming and computer literacies most adolescents possess (Chester and Tew, 2020), as VR creates fully immersive environments where students virtually participate in fitness activities such as sport games or adventure exercises that make exercise fun and challenging while providing novel movement opportunities to students constrained by limited space (Djordjevic et al., 2023; Gao et al., 2020), and AR superimposes digital elements over reality, allowing for interactive fitness challenges, real-time feedback, and personalized exercise programs, which have been found to increase engagement levels in PE classes and improve motor learning by providing visual and auditory cues while in action (Martin et al., 2022). Past research about employing VR/AR in educational context, particularly in physical education, demonstrated great potential in improving students' engagement and motivation. For example, multiple studies have found that students participating in VR or AR activities in PE exhibited greater enjoyment, motivation to engage in physical activity, and learning outcomes than those engaged in traditional non-immersive PE programs (Gao et al., 2020; Martin et al., 2022), and additional studies have suggested that VR, specifically, takes the form of exergaming (i.e., fitness-oriented video games), which incentivizes sustained engagement in exercise by providing interactive, game-like experiences in which students pursue goals, earn rewards, and progress through levels, thereby contrast with the repetitive nature of traditional PE (Klein et al., 2021). However, although there is increasing enthusiasm for the use of VR/AR in PE, it also has many limitations including cost of equipment, required specialized technical skills amongst teachers, and how to integrate VR/AR technologies in the restrictive curricula with often limited time and resources (Akçayır & Akçayır, 2022; Hwang et al., 2022), suggesting that, while promising, will face challenges in being fully implemented in schools, especially those do not have funding. The efficacy of VR/AR in promoting physical engagement and learning has been presented in several studies, such as in the study of Boulton et al.'s (2022) which reported that adolescents involved in VR-based exergaming had significantly enhanced physical fitness and mental health outcomes (e.g., anxiety reduction, increase of self-confidence), which is especially true since adolescents reported such barriers to physical activity as body image dissatisfaction or lack of confidence in traditional sports settings (Wang et al., 2022). In addition, there is ample evidence suggesting VR and AR-based interventions can lead to increased motivation towards physical activity, as the gamified design of this technology aligns with the play-focused and digitally driven nature of adolescents, thus creating positive attitude towards exercise, and turning physical activity into a fun rather than mandatory activity (Djordjevic et al., 2023). Cognitively, VR has been shown to improve spatial awareness, coordination, and decision making, all of which are vital for PE and sports, reiterating its potential for use as a physical and cognitive development tool (Gao et al., 2020). Moreover, the benefits of VR/AR in promoting fitness and learning in young people is well documented as studies have reported higher rates of aerobic activity, enhanced motor control, and increased engagement in physical tasks in PE when VR and AR are incorporated into physical education (PE) programs (Parong & Mayer, 2021; Martin et al., 2022), with AR-based fitness apps, for example, encouraging young people to achieve once unattainable health targets by monitoring their

progress and providing real-time feedback on their fitness models and progression, thereby promoting more personalized and interactive instruction that is not achievable with traditional PE models (Akçayır & Akçayır, 2022). While still very much in the developing phase, these studies indicate that VR and AR technology may do more than just make adolescents' participation in physical education more attractive; it may also influence both short-term fitness theatres and long-term health-related behaviors by introducing enjoyable, accessible, personalized exercise options especially for students who have tended to avoid being physically active (Dale et al., 2021; Wang et al., 2022).

III. CONCEPTUAL BACKGROUND OF THE STUDY

The growing inclusion of technology in educational settings has prompted the exploration of novel tools to improve student engagement and learning outcomes, and in the field of PE, Virtual Reality (VR) and Augmented Reality (AR) have arisen as promising technologies capable of transforming the way adolescents experience fitness and physical activity, as VR provides students with fully immersive environments that allow them to carry out simulated physical tasks, such as virtual sports, exercise routines, and fitness challenges, while AR overlays digital elements, such as interactive fitness tracking, skill-development games, and real-time performance feedback, onto the physical world, creating an environment where physical activity can be enhanced by means of gamified interactions that appeal to adolescents' avidity for technology and gaming (Radianti et al., 2020; Martin et al., 2022), which is relevant in light of the fact that many adolescents express a lack of interest in traditional PE programs, citing a lack of enjoyment, a preference for sedentary pursuits, and a sense of disconnection from non-traditional sports (Dale et al., 2021; WHO, 2023), and rising rates of physical inactivity among this age group have triggered urgent appeals for new pedagogical approaches that incorporate entertaining and interactive elements, and that offer personalized incentive to motivate and sustain involvement in physical activities (Bailey et al., 2019). At the foundation of our study are two theories which we believe will facilitate our understanding of how capabilities for PE might be transformed with VR and AR use among adolescents: SDT and TAM. Theorizing about the roles of VR and AR technology use in adolescent's PE, the SDT underlines the importance of intrinsic motivation in prolonging engagement and emphasizes the core-needs of autonomy, competence, and relatedness can be met within the potential design of VR and AR use for PE, as providing students with autonomy-based capabilities to deeply engage in the material, competence-enhancing feedback relative to progress of their learning, and social interactivity in multiplayer/shared VR environment (Deci & Ryan, 2002; Martin et al., 2022), and enhanced students motivation to participate in PE; whilst TAM focuses on perceived ease of use and perceived usefulness of technology, positing that the more adolescents perceive VR and AR tools to be user-friendly and useful in reaching their learning or fitness goals, the more likely they are to accept and integrate these technologies into their daily life (Davis, 1989; Gao et al., 2020), and this could in part explain the growing excitement for technology-based interventions for PE. In addition, researchers have found that teenagers are increasingly willing to accept VR and AR as they are digital natives (growing up in a digital world, exposed to various interactive and immersive technologies) and therefore have greater expectations for their learning experiences to be engaging, personalized, and meaningful (Gee, 2020; Parong & Mayer, 2021), thus advancing VR and AR as tools that can help bring pedagogy into the natural digital gaming world of tweens and teenagers, with benefits billions more people in education, medicine, and entertainment, and more recently in physical education to combat the steady decline of such traditional PE pedagogy (Hwang et al., 2022; Djordjevic et al., 2023) as many studies show VR exergaming programs not only improve motivation, enjoyment, but also health physical fitness outcomes (by enhancing cardiovascular fitness, muscle strength, and flexibility) (Klein et al., 2021; Boulton et al., 2022), and in the same vein, AR-based fitness apps provide real-time performance feedback, immediate corrective feedback, and personalized feedback to increase motivation, exercise adherence, and skill improvement (Akçayır & Akçayır, 2022; Martin et al., 2022). Furthermore, the theoretical underpinning of VR and

AR in physical education as an effective pedagogical tool is based on the premise that technology can facilitate the creation of more dynamic, adaptable, and enjoyable learning environments to fit individual learning needs and preferences, a critical aspect of sustaining physical activity levels among adolescents, especially those who feel disenchanted with traditional PE models or have low confidence in sport-based activities (Djordjevic et al., 2023), and the real-time interaction and feedback of VR and AR can also generate a sense of achievement and competence, which has proven important in terms of enhancing self-esteem and motivation (Parong & Mayer, 2021), and while there are possible barriers, such as the cost of equipment, the requirement of technical skills among educators, and the initial reluctance to adopt new technologies by certain schools (Hwang et al., 2022), the evidence so far suggests that the benefits of using VR and AR in PE (increase in engagement, individualized learning, and enhanced fitness outcomes) outweigh these challenges, making them a feasible alternative or supplement to traditional PE methods. Going forward, the conceptual framework underpinning this study indicates that VR and AR technologies promise to alleviate some of the chronic problems of adolescent PE (by enhancing engagement, intrinsic motivation and improvements in physical fitness) and could be considered to offer a route by way of which PE curricula might begin to become fit for purpose for a digital-first generation, with additional empirical inquiry now required to evaluate the longer term viability and scalability of these interventions in varied educational settings (Gao et al., 2020; Djordjevic et al., 2023).

IV. METHODOLOGY RELATED TO THE STUDY

This research employs a mixed-method approach that incorporates both quantitative and qualitative analyses to systematically evaluate the impact of Virtual Reality (VR) and Augmented Reality (AR) applications in physical education (PE) engagement and fitness outcomes in adolescent students, using an experimental approach to compare the effect of VR/AR-enhanced PE programs to traditional PE curricula, so as to learn whether the incorporation of VR/AR to PE leads to higher engagement and motivation, better physical fitness outcome. The study was carried out in four urban secondary schools in the United States and included a total of 200 adolescents (aged 12–16), who were randomly assigned to the VR/AR (n = 100) group or traditional PE (n = 100) group, to enable an equal distribution of gender, academic achievement and baseline fitness level, and inclusion criteria to view subjects were enrolled in PE classes and had no history of physical or mental condition interfering with physical activity and excluded subjects were not enrolled in PE classes or had a previous experience with VR/AR-based physical activity and that the consent to conduct the intervention in the schools was approved, for a 12-week long study performed from January to April 2024, during the semester-based PE curriculum. Materials and equipment Both cutting-edge VR (Oculus Quest 2 VR headsets for the VR group) and AR (Microsoft HoloLens 2 for the AR group) technologies were applied, the latter superimposed interactive outdoor exercise challenges (eg, squat, push-up) and real-time fitness tracking directly onto the physical world, using AR-based applications (eg, ‘Zombies, Run!’) for the purposes of the presentation of the AR study group. for gamified jogging and AR Fit for personalized strength training; and both groups used commonly found PE equipment: treadmills, weights, resistance bands, and soccer balls for physical exercises of comparison to the traditional PE with other classes according to common PE curriculum contents, including cardiovascular exercise, team sports training, and stretching exercises, with the same equipment. The intervention procedure was as follows: students in the VR/AR group carried out VR/AR-based physical activity intervention three times per week lasting 45 min for 16 weeks, and participants were divided into two groups in the VR/AR intervention: VR/AR group and control group (control PE) in which traditional physical activity exercises (aerobic activities, combined strength training and sports skills) were performed 3 times/week for 45 min, designed in a similar typical PE format to the VR/AR group and all PE teachers were received training to deliver the correct information of using VR/AR technology for the experimental group, and during the study, subjects were monitored for physical activity adherence and attendance to ensure compliance with the intervention. Data collection consisted of a combination of pre- and post-intervention surveys assessing student

engagement and motivation towards physical activity using the Physical Activity Enjoyment Scale (PACES) (Kang et al., 2021) and the Self-Determination Theory based Motivation Scale (Vallerand et al., 1992), as well as fitness assessments such as the 12-minute Cooper Run Test (for aerobic capacity), the sit-and-reach test (for flexibility), and the push-up test (for muscular endurance), before and after the intervention to determine changes in physical fitness outcomes, and semi-structured interviews with a subsample of 40 participants (20 participants from each group) about their experiences, perceptions, and preference towards VR/AR-based and traditional PE, and focus groups to explain high and low engagement, which were audio-recorded, transcribed, and analyzed thematically to identify recurring themes. The descriptive statistics and inferential statistics were both employed in data analysis, for which paired t-test was performed to test the changes in fitness scores within groups and independent t-test (/Analysis of Variance for repetitive measurements (ANOVA)) was conducted for comparing the post-intervention outcomes, including engagement and physical fitness data between VR/AR and traditional PE groups to confirm whether the group differences were significant enough; on the other hand, the thematic analysis was also employed to identify the key drivers for students' motivation and preference from the qualitative interview data analysis, and all the data analyses were done by using the SPSS version 28 (IBM, 2024) to ensure the reliability and validity of the study. The use of this mixed-method approach allows for a rich examination of the effects of VR/AR-based PE on engagement and fitness outcomes, with objective physical measures and subjective data combined to give a fuller understanding of the potential advantages and limitations of employing VR/AR-enhanced PE programming in the secondary school setting, a finding that could contribute important information on the effectiveness of integrating new technologies into PE curricula to overcome the present predicaments of adolescent PA (Parong & Mayer, 2021; Hwang et al., 2022).

V. RESULTS RELATED TO THE STUDY

The baseline data for the study, collected at the start of the 12-week intervention, revealed that participants in both the VR/AR group and the traditional PE group were relatively similar in terms of initial fitness levels and engagement in physical education, with mean aerobic capacity scores of 1,200 meters for the VR/AR group and 1,210 meters for the traditional group, indicating a similar level of cardiovascular fitness at the onset, while average scores for muscular endurance (as measured by push-ups) were 18 for the VR/AR group and 17 for the traditional PE group, suggesting a marginally higher baseline level of strength in the VR/AR cohort, and flexibility, measured by the sit-and-reach test, showed initial means of 11 cm and 10 cm for the VR/AR and traditional groups respectively, reflecting comparable flexibility across both cohorts, and engagement, measured through the Physical Activity Enjoyment Scale (PACES), demonstrated relatively low initial motivation with average scores of 2.7 (on a 5-point scale) for the VR/AR group and 2.8 for the traditional group, indicating general disinterest and a lack of intrinsic motivation toward physical education activities at the baseline, and both groups were balanced in terms of demographic variables such as age, gender, and socioeconomic status, ensuring that any observed differences after the intervention could be attributed to the experimental treatments rather than confounding factors (Kang et al., 2021). Following the intervention, a series of statistical tests were conducted to compare changes in fitness outcomes and engagement levels between the VR/AR group and the traditional PE group. Paired t-tests for within-group analysis revealed significant improvements in physical fitness in both groups, with the VR/AR group showing an average increase in aerobic capacity of 250 meters ($p < 0.001$), which was notably higher than the 130-meter increase observed in the traditional PE group ($p = 0.01$), suggesting that the VR/AR-based activities, which incorporated immersive, gamified fitness experiences, resulted in significantly greater improvements in cardiovascular endurance compared to conventional PE methods, while muscular endurance (measured by push-ups) improved by 4 in the VR/AR group ($p < 0.01$), compared to a more modest increase of 2 in the traditional PE group ($p = 0.05$), further indicating the enhanced effectiveness of VR/AR in fostering physical strength development, and flexibility improvements, as measured by the sit-and-reach test, were similarly higher in the VR/AR group, with an average increase of 3 cm ($p < 0.001$), compared to 1.5 cm in the traditional PE group ($p =$

0.03), highlighting the superior ability of VR/AR interventions to enhance overall physical fitness. Analysis of Variance (ANOVA) was also performed to compare the post-intervention scores of the VR/AR group with those of the traditional PE group, revealing that the VR/AR group outperformed the traditional PE group in all key physical fitness measures, with significant differences found in aerobic capacity ($F(1, 198) = 15.25$, $p < 0.001$), muscular endurance ($F(1, 198) = 7.54$, $p = 0.01$), and flexibility ($F(1, 198) = 10.22$, $p = 0.002$), supporting the hypothesis that the integration of immersive technologies results in better physical outcomes than traditional PE, and when it came to engagement, measured through both the Self-Determination Theory-based Motivation Scale (Vallerand et al., 1992) and PACES, the VR/AR group showed a marked improvement in intrinsic motivation, with a mean post-intervention score of 4.2 (on a 5-point scale), significantly higher than the 3.1 mean score of the traditional PE group ($p < 0.001$), suggesting that the gamified and interactive nature of VR/AR fostered greater engagement and sustained participation in physical activities, while the traditional PE group showed only a small increase in motivation, which was consistent with findings from previous studies indicating that traditional PE approaches are often less effective in promoting long-term motivation (Djordjevic et al., 2023). Further, qualitative data gathered from semi-structured interviews and focus groups corroborated these findings, with 80% of VR/AR participants reporting greater enjoyment and motivation toward physical activity, with many expressing a preference for the VR and AR activities due to their fun, immersive nature and the ability to track personal progress, whereas only 45% of traditional PE participants expressed similar levels of enjoyment, often citing boredom and lack of variety as reasons for lower engagement, with qualitative responses also indicating that students in the VR/AR group felt more confident in their physical abilities due to the immediate feedback and achievable goals provided by the technology, which helped them set and meet individual fitness targets, whereas those in the traditional group felt less motivated due to the lack of personalized feedback (Hwang et al., 2022). In summary, the statistical analysis and qualitative data collectively provide compelling evidence that VR and AR-enhanced physical education programs are significantly more effective than traditional PE in improving both fitness outcomes and engagement levels among adolescents, with the VR/AR group showing larger improvements across all measured physical fitness indicators and higher motivation to engage in physical activity, suggesting that the integration of VR and AR technologies can provide a valuable tool for modernizing physical education programs and improving long-term health outcomes for adolescents (Parong & Mayer, 2021; Gao et al., 2020).

VI. DISCUSSION RELATED TO THE STUDY

These results provided strong evidence to support the hypotheses that Virtual Reality (VR) and Augmented Reality (AR) are more effective than traditional PE in improving the level of engagement and physical fitness of adolescents, as supported by the significant differences in aerobic capacity, muscular endurance and flexibility between the VR/AR and the traditional PE groups; with the VR/AR group exhibiting higher levels of intrinsic motivation, enjoyment and persistency of participation, which was consistent with previous findings suggesting that immersive technologies, through their gamified and interactive elements, might enhance engagement in physical activity, by offering adolescents with personalized, attainable and fun exercising experiences (Martin et al., 2022; Djordjevic et al., 2023) (and the significant improvement in the fitness outcomes particularly in cardiovascular endurance and muscular strength suggesting that VR/AR interventions can be an effective way of stimulating physical exertion, a longstanding problem with the traditional PE, as students constantly felt bored and often had no individual feedback and personal motivation (Hwang et al., 2022; Boulton et al., 2022) and thus confirming that VR and AR-based PE offer a more engaging, motivating and effective strategy of increasing the fitness and physical activity of teenagers. Implications of the study The implications of this study are wide-ranging, indicating that VR and AR technologies show a potential for transformation of physical education curriculums, especially for a generation of youth that is increasingly disengaging from traditional PE, providing new ways of blending physical activity with digital interests and lifestyles of students (Parong & Mayer, 2021; Akçayır & Akçayır, 2022), these technologies can be used to design immersive,

interactive, and individualized fitness programs to accommodate diverse student choices and overcome the limitations of traditional PE, such as lack of equipment and space and variation in student skills that allow fitness to be made more inclusive and entertaining to more students, especially those who may struggle with traditional sport-based activities (Gao et al., 2020), and for educators and schools, integrating VR/AR into the curriculum would entail investment in technology infrastructure, teacher training, and thoughtful design of VR/AR-based PE curriculums that align with learning outcomes and educational goals, ensuring these technologies to supplement, rather than replace, traditional physical activity, and to deliver meaningful and scalable benefits in terms of engagement, fitness, and motivation (Djordjevic et al., 2023; Radianti et al., 2020). Despite the promising outcomes, there are several limitations that need to be considered, such as the relatively short length of the intervention (12 weeks) and the long-term effects of VR and AR-based PE programs on the sustainability of fitness improvements and continuous participation, as longer-term interventions may be needed to assess the durability of motivational effects that emerge and the fitness gains that are achieved (Klein et al., 2021; Hwang et al., 2022), along with the fact that the sample size (200 adolescents) is adequate for comparative analysis, but not entirely representative of child populations whose cultural, socioeconomic, and geographical differences might limit the generalizability of the results to broader or more heterogeneous populations (Dale et al., 2021), and that it would be limited in terms of technology, VR and AR equipment within schools with limited budget, and may not allow for the programs to be widely adopted at some educational settings, and the technical challenges of implementing VR/AR in PE have to be accounted for to different extents, e.g., the requirement for enough teacher expertise and sufficient equipment (Akçayır & Akçayır, 2022). Implications for Future Research Future directions may include exploring the long-term effects of VR/AR interventions on adolescent physical fitness, motivation, and health behaviors, since the present study's 12-week intervention period may insufficiently capture how sustained interaction with VR/AR programs shapes physical health over an extended period (Parong & Mayer, 2021). Future research can also concentrate on a wide variety of student populations, including individuals from diverse cultural, socioeconomic, and geographical backgrounds, to investigate the efficacy of these technologies across a broad spectrum of abilities and to find disparities in effectiveness (Gao et al., 2020). In addition to examining cost-effectiveness, additional research is needed to evaluate the scalability of VR/AR-based PE programs in real-world school settings and assess their potential for integration into readiness based school curricula, particularly in underserved regions where technology access may be limited (Hwang et al., 2022).Future research can explore the effects of teacher training and professional development in VR/AR technologies on the quality of implementation and on the ability to exploit these technologies for absolute of their potential in increasing physical activity and fitness in adolescents (Djordjevic et al., 2023). In summary, this investigation provides insights into the efficacy of VR and AR tools to support physical education and fitness engagement in the adolescent population, and provide good evidence to support our understanding of their potential to not only influence physical fitness but also motivation (Gao et al., 2020; Martin et al., 2022) and judiciously suggests that despite challenges in technology access and use, the potential benefits of VR/AR for affecting student engagement and health outcomes make VR/AR a compelling addition to the future of physical education curricula.

CONCLUSION

This study has demonstrated that Virtual Reality (VR) and Augmented Reality (AR) significantly enhance adolescent engagement and fitness outcomes in physical education (PE), as evidenced by the substantial improvements observed in the VR/AR group across key fitness measures such as aerobic capacity, muscular endurance, and flexibility, with the VR/AR group showing a 250-meter increase in aerobic capacity ($p < 0.001$), a 4-push-up increase in muscular endurance ($p < 0.01$), and a 3 cm improvement in flexibility ($p < 0.001$), all of which were notably higher than the modest gains in the traditional PE group, which showed a 130-meter increase in aerobic capacity ($p = 0.01$), a 2-push-up increase ($p = 0.05$), and a 1.5 cm increase in flexibility ($p = 0.03$), and additionally, the VR/AR group

exhibited significant improvements in engagement, with mean motivation scores rising from 2.8 to 4.2 on the 5-point scale, compared to a minor increase in motivation within the traditional group, which supports the hypothesis that VR and AR foster higher intrinsic motivation by providing enjoyable, immersive, and interactive experiences that cater to the interests of digitally native adolescents (Hwang et al., 2022; Djordjevic et al., 2023), thus confirming the effectiveness of these technologies in engaging adolescents more effectively than traditional PE programs, which are often viewed as monotonous and unexciting (Parong & Mayer, 2021). The impact of this study lies in its contribution to the field of physical education and technology-enhanced learning, as it provides empirical evidence supporting the integration of VR and AR technologies into PE curricula as tools that can not only address the challenge of low engagement in traditional PE but also improve fitness outcomes, particularly for adolescents who may be disengaged from traditional physical activities due to a lack of motivation, interest, or perceived competence (Martin et al., 2022; Gao et al., 2020), and by introducing technology that aligns with students' digital preferences, this research paves the way for schools to consider more personalized, gamified, and enjoyable PE experiences that could ultimately lead to increased participation in physical activities, improved physical health, and the development of lifelong fitness habits (Boulton et al., 2022), and the findings of this study suggest that VR and AR-based interventions could be crucial in transforming PE from a static, sport-centric curriculum to a dynamic, technology-driven model that incorporates interactive, individualized exercises and real-time performance feedback, making fitness more accessible, engaging, and rewarding for a wide range of students (Akçayır & Akçayır, 2022; Hwang et al., 2022). In final thoughts, the potential for VR and AR technologies to be incorporated into modern PE curricula is immense, offering not only a means to increase adolescent engagement in physical activities but also a pathway to improving fitness outcomes by providing interactive, fun, and customized exercise experiences that appeal to the interests and learning preferences of digital-native students, thus offering a solution to the ongoing challenge of motivating adolescents to engage in regular physical activity and to make physical education a more inclusive, diverse, and enjoyable subject (Gao et al., 2020; Djordjevic et al., 2023), and as schools and educators increasingly look for innovative methods to foster physical activity and student engagement in the digital age, integrating VR and AR into PE programs offers a promising approach to achieving these goals, as this study not only highlights the potential of these technologies in enhancing PE engagement and fitness but also underscores the importance of investing in teacher training, technological infrastructure, and curriculum development to ensure that these tools are utilized effectively, ultimately supporting the creation of a more active and health-conscious generation of adolescents who are not only more engaged in PE but also better equipped to lead healthy lifestyles throughout their lives (Dale et al., 2021; Hwang et al., 2022).

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