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ORIGINAL

Augmented reality's impact on STEM learning

Realidad aumentada y su impacto en el aprendizaje STEM

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ABSTRACT

Introduction: Augmented Reality (AR) is an emerging technology with potential to enhance STEM (Science, Technology, Engineering, and Mathematics) education. This study investigates the impact of implementing AR in STEM learning.
Objectives: to evaluate the effectiveness of AR in enhancing students' motivation, understanding, academic performance, and problem-solving abilities in STEM disciplines.
Method: a mixed methods approach with a quasi-experimental design was employed. The study involved 180 university students and 12 STEM instructors from various programs. Data collection methods included standardized tests, questionnaires, interviews, observations, and artifact analysis.
Results: the AR group showed significant improvements in academic performance, motivation, and attitudes toward STEM subjects compared to the control group. Qualitative data supported AR's potential to create more engaging and interactive learning experiences. Students reported better understanding of complex concepts and increased interest in STEM fields.
Conclusions: integrating AR in STEM education can enhance academic performance, motivation, attitudes, and comprehension of complex concepts. These findings support the importance of exploring and implementing AR technology in STEM educational settings to improve learning outcomes and foster student engagement.

Keywords: Educational Technology; Problem Solving; Motivation; Learning.

RESUMEN

Introducción: la Realidad Aumentada (RA) es una tecnología emergente con potencial para mejorar la educación STEM (Ciencia, Tecnología, Ingeniería y Matemáticas). Este estudio investiga el impacto de implementar la RA en el aprendizaje STEM.
Objetivos: evaluar la efectividad de la RA para mejorar la motivación, comprensión, rendimiento académico y habilidades de resolución de problemas de los estudiantes en las disciplinas STEM.
Métodos: se empleó un enfoque de métodos mixtos con un diseño cuasi-experimental. El estudio involucró a 180 estudiantes universitarios y 12 instructores STEM de varios programas. Los métodos de recolección de datos incluyeron pruebas estandarizadas, cuestionarios, entrevistas, observaciones y análisis de artefactos.
Resultados: el grupo de RA mostró mejoras significativas en el rendimiento académico, motivación y actitudes hacia las asignaturas STEM en comparación con el grupo de control. Los datos cualitativos respaldaron el potencial de la RA para crear experiencias de aprendizaje más atractivas e interactivas. Los estudiantes reportaron una mejor comprensión de conceptos complejos y un mayor interés en los campos STEM.
Conclusiones: la integración de la RA en la educación STEM puede mejorar el rendimiento académico, la motivación, las actitudes y la comprensión de conceptos complejos. Estos hallazgos apoyan la importancia de explorar e implementar la tecnología de RA en entornos educativos STEM para mejorar los resultados de aprendizaje y fomentar la participación de los estudiantes.

Palabras clave: Tecnología Educativa; Resolución de Problemas; Motivación; Aprendizaje.

INTRODUCTION

In the current digital era, the integration of innovative technologies in the field of education has become fundamentally important. Augmented Reality (AR), a technology that combines virtual elements with the real world, has emerged as a promising tool to enhance teaching and learning processes, especially in the areas of Science, Technology, Engineering and Mathematics (STEM). The importance of fostering interest and performance in these disciplines is crucial for economic and social development, driving innovation, competitiveness, and the resolution of complex problems.[1,2]

However, traditional methods often face challenges such as lack of motivation, difficulty in visualizing abstract concepts, and the gap between theory and practice.[3,4] AR offers a solution by allowing the visual and interactive representation of complex content, facilitating understanding, learning, and practical application of concepts.[5,6]

Numerous studies have explored the potential of AR in different educational and geographical contexts, demonstrating its effectiveness in increasing motivation, comprehension, and performance in areas such as chemistry[7], physics[8], and mathematics.[9]

AR offers key benefits such as enhancing the visualization and understanding of abstract and complex concepts[10,11,12], increasing motivation and engagement[13,14,15], facilitating the connection between theory and practice[16,17,18], and fostering the development of higher cognitive skills such as critical thinking and problem-solving.[19,20,21]

AR has found applications in various STEM disciplines, such as visualizing 3D models in biology[22,23,24], exploring molecular structure in chemistry[7,25,26], facilitating the understanding of abstract concepts in physics[8,27,28], visualizing designs and prototypes in technology and engineering[29,30,31], and manipulating 3D geometric objects and visual representations in mathematics.[9,19,32,33,35]

Despite the benefits, there are challenges and considerations, such as the potential for visual information overload and excessive cognitive load[10,21,36], technical difficulties[37,38,39], instructional design and curricular alignment[10,16,21], costs and accessibility[37,38], contextual factors such as educational level and available resources[10,15,40], resistance to change and the need for teacher training.[7,16]

To fully leverage the potential of AR, it is crucial to adopt sound pedagogical approaches and effective implementation strategies, such as student-centered learning, exploratory tasks, problem-solving and project-based learning[10,21,41], appropriate scaffolding and feedback[10,19,21], combination with other strategies such as direct instruction and collaborative learning[15,19,38], and professional development for teachers focused on the effective use of AR.[7,10,16]

Although the field has progressed, there are still areas that require further research, such as the integration of AR with other emerging technologies[16,10,40], the development of key 21st-century skills[7,10,19], ubiquitous and mobile learning[16,10,24], game-based and gamification approaches[10,15,24], assessment of long-term impact[10,24,40], and the development of solid theoretical and methodological frameworks.[10,21,37]

The objective is to analyze the impact of AR on STEM learning, evaluating its effectiveness in improving motivation, comprehension, performance, and problem-solving. It is hypothesized that AR will provide a more attractive, interactive, meaningful, and practical learning experience, leading to greater engagement, academic achievement, and problem-solving skills.

METHOD

The research on the impact of Augmented Reality (AR) on STEM learning utilized a mixed methods approach, combining quantitative and qualitative methods under a quasi-experimental design. A non-probability sample of 180 university students from various STEM majors at the University of Guayaquil was selected and randomly assigned to an experimental group and a control group. Additionally, 12 STEM faculty members were included to understand the facilitators' perspectives and experiences in implementing AR in the classroom from a pedagogical viewpoint.

The study focuses on students enrolled in STEM programs at the University of Guayaquil who are 18 years or older, proficient in the language of instruction, and willing to participate in AR-enhanced learning activities. However, students diagnosed with severe cognitive impairments, those unable to attend at least 80 % of the scheduled sessions, or those participating in other educational technology studies concurrently will be excluded from the research.

For faculty participants, the study includes those teaching STEM courses at the University of Guayaquil with a minimum of 2 years of teaching experience in higher education and who are willing to integrate AR technology into their teaching methods. Faculty members planning to take a leave of absence during the study period or unable to commit to the required training sessions on AR implementation will be excluded from participation.

The total population of STEM students at the University of Guayaquil is approximately 5,000. Using a confidence level of 95 % and a margin of error of 7,2 %, the required sample size was calculated to be 180 students. The formula used was n = [Z^2 * p * (1-p) * N] / [e^2 * (N-1) + Z^2 * p * (1-p)]. In the sample size calculation formula, the variables are defined as follows: n represents the sample size, Z equals 1,96 (for a 95 % confidence level), p is 0,5 (assumed population proportion), N corresponds to 5,000 (population size), and e is 0,072 (margin of error).

This sample size ensures that the results can be considered representative of the larger population of STEM students at the university. This mixed methods approach allowed for a deeper and more holistic understanding of the studied phenomenon by combining numerical data and experiential perspectives, providing greater robustness and validity to the research findings.

In this research on the impact of Augmented Reality (AR) on STEM learning, various instruments were used to collect quantitative and qualitative data. Standardized academic performance tests and questionnaires on motivation, attitudes, and perceptions were administered to students before and after the AR intervention. Additionally, semi-structured interviews were conducted with participating teachers to gather detailed information about their experiences and perceptions. Systematic observations of AR classes were carried out, recording field notes on behavior, participation, and strategies employed. Finally, student artifacts such as assignments and productions were analyzed to evaluate their understanding and application of concepts. This combination of quantitative and qualitative instruments allowed for a comprehensive view of the studied phenomenon from multiple sources and perspectives.

In this research, the quantitative data obtained from tests and questionnaires were analyzed using appropriate statistical methods. Specifically, paired t-tests were employed to evaluate changes within groups before and after the augmented reality (AR) intervention. Independent samples t-tests were used to compare results between the experimental and control groups. Analysis of variance (ANOVA) was utilized to assess differences across multiple variables, while analysis of covariance (ANCOVA) allowed for controlling the effect of covariates such as prior academic performance, age, gender, and socioeconomic status.

The confidence level for all statistical tests was set at 95 %, corresponding to a critical p-value of 0,05. This means that results were considered statistically significant if the calculated p-value was less than 0,05, indicating a 5 % or lower probability that the observed differences occurred by chance. For example, the ANCOVA results comparing the increase in academic performance between the experimental and control groups yielded $F(1, 177) = 38{,}24$, $p < 0{,}001$, which is well below the critical p-value, thus indicating a statistically significant difference.

This rigorous statistical approach allowed for a comprehensive comparison of results between the experimental and control groups, a detailed evaluation of changes before and after the AR intervention, and a careful consideration of potential confounding variables, all while maintaining a high degree of confidence in the findings. On the other hand, qualitative data from interviews, observations, and artifacts were coded and analyzed following a grounded theory approach, utilizing content analysis and thematic analysis techniques to identify patterns, emerging themes, perspectives, and relevant experiences regarding the use of AR in STEM learning. Additionally, a triangulation of quantitative and qualitative data was performed to obtain a more comprehensive and robust understanding of the studied phenomenon, contrasting and complementing numerical findings with the perspectives and lived experiences of the participants. This rigorous methodological design, combining quantitative and qualitative methods, and data triangulation, allowed for a comprehensive and valid understanding of the impact of AR on STEM learning, supported by robust empirical data and valuable experiential perspectives from multiple sources.

This study was conducted with utmost adherence to ethical principles for human subject research, as outlined in the Declaration of Helsinki and institutional guidelines. The University of Guayaquil's Institutional Review Board (IRB) meticulously reviewed and approved the research protocol, encompassing study design, data collection methods, and participant safeguards. All participants were provided comprehensive information about the study and gave written informed consent, with students assured that their academic standing would not be affected by their participation decision. Stringent confidentiality measures were implemented, including data anonymization and secure storage. The voluntary nature of participation and the right to withdraw were emphasized, while the study design minimized potential risks, particularly concerning the use of AR technology. Equitable participant selection was ensured, avoiding unfair inclusion or exclusion based on demographic factors. Post-study, all participants were debriefed, with control group students offered the opportunity to experience AR-enhanced learning modules. Any potential conflicts of interest were disclosed and managed appropriately. Through rigorous adherence to these ethical principles, the study maintained the rights and well-being of all participants, thereby upholding its integrity and credibility.

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RESULTS

In this section, the detailed findings obtained in the research on the impact of Augmented Reality (AR) on STEM learning are presented. The data collected through multiple instruments is analyzed objectively and without value judgments, providing a comprehensive and robust perspective of the studied phenomenon.

Quantitative Analysis

Academic Performance in Science and Mathematics

Table 1. Academic Performance Test Results

Group	Pre-test	Post-test	Difference
Experimental (AR)	68,4 (12,2)	82,7 (10,5)	+14,3
Control (Traditional)	69,1 (11,8)	73,6 (12,1)	+4,5

As observed in table 1, the experimental group that received instruction with AR experienced a significant increase in their academic performance in science and mathematics, with an average increase of 14,3 points on the standardized test scores. This increase is substantially higher than that of the control group, which received traditional instruction and showed an average increase of only 4,5 points. An analysis of covariance (ANCOVA) revealed that this difference in the increase in academic performance between the experimental and control groups was statistically significant ($F(1, 177) = 38,24$, $p < 0,001$), even after controlling for prior academic performance and other demographic variables such as age, gender, and socioeconomic status.

These quantitative results support the hypothesis that the integration of AR in the STEM teaching-learning process can lead to substantial improvements in students' academic performance, compared to traditional instructional methods.

Motivation, Attitudes, and Perceptions

Table 2. Results of Motivation, Attitudes, and Perceptions Questionnaires

Evaluated Aspect	Experimental (AR)		Control (Traditional)	
	Pre	Post	Pre	Post
Motivation	3,2 (0,8)	4,6 (0,5)	3,1 (0,9)	3,4 (0,7)
Attitudes towards STEM	3,7 (1,1)	4,8 (0,6)	3,8 (1,0)	4,1 (0,9)
Perception of usefulness	4,1 (0,9)	4,9 (0,4)	4,0 (0,8)	4,2 (0,7)

In addition to the impact on academic performance, the questionnaire results (table 2) revealed a significant positive effect of AR on key affective and attitudinal aspects related to STEM learning.

In the experimental group that used AR, a considerable increase was observed in students' motivation towards STEM learning, from a mean of 3,2 to 4,6 on the Likert scale. This increase was much higher than that experienced by the control group, which showed a more modest increase from 3,1 to 3,4.

Similarly, positive attitudes towards STEM disciplines were notably improved in the experimental group, with an increase from 3,7 to 4,8, compared to a smaller increase from 3,8 to 4,1 in the control group.

Furthermore, the perception of usefulness of the learned STEM content and skills was also favored by the use of AR, with an increase from 4,1 to 4,9 in the experimental group, compared to a more modest increase from 4,0 to 4,2 in the control group.

These findings suggest that the integration of AR in the STEM teaching-learning process not only improves academic performance but also has a positive impact on motivational factors, attitudes, and the valuation of these disciplines by students.

Qualitative Analysis

Teacher Interviews

The semi-structured interviews conducted with the teachers participating in the implementation of augmented reality (AR) in the classroom provided valuable insights into the experiences, challenges, and opportunities associated with this technology. Most highlighted the potential of AR to capture students' interest and attention, especially in complex or abstract topics, facilitating the understanding of concepts through the visualization and manipulation of 3D models and digital information overlaid on the real world. Additionally, several teachers highlighted the increase in student participation and engagement during AR lessons. However, they also identified significant challenges, such as the required technical learning curve, technical issues, the

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need for additional training, and time management in the classroom to effectively integrate AR into lessons. Despite these challenges, most expressed their enthusiasm for continuing to explore and improve the use of AR in their teaching practices, recognizing its potential to enhance student learning in STEM.

Classroom Observations

The classroom observations conducted during lessons involving augmented reality (AR) provided a direct and detailed perspective of the impact of this technology on the learning environment and classroom dynamics. In general, a higher level of participation, engagement, and collaboration among students in the experimental group using AR was observed compared to traditional classes. Students appeared excited and curious to explore the content through AR applications, fostering a more active, dynamic, and interactive learning environment. During AR activities, students actively participated, asking questions, sharing ideas, and working in teams to manipulate and explore models and simulations, suggesting a higher level of engagement and internalization of learning. Additionally, students demonstrated a greater ability to visualize and understand abstract or complex concepts when presented through AR. However, some challenges were also identified, such as occasional technical difficulties that required intervention or technical support, which could disrupt the flow of the lesson and cause distractions.

Artifact Analysis

The analysis of projects, tasks, and productions carried out by the students in the experimental group that used augmented reality (AR) provided additional evidence of the positive impact of this technology on the understanding and practical application of STEM concepts. In general, the artifacts produced by this group demonstrated a deeper and more detailed understanding of the complex phenomena and systems studied. For example, in reports and presentations on physics concepts, students were able to represent and explain the underlying principles more accurately and visually, using the visualizations and simulations provided by the AR applications. Additionally, it was observed that these students were able to apply their knowledge more effectively in solving practical problems and designing innovative solutions, such as using AR to visualize and manipulate virtual prototypes in engineering projects. In contrast, the artifacts produced by the control group tended to be more descriptive, with more abstract explanations and a lesser ability to represent and apply concepts in a practical manner.

DISCUSSION

The results obtained align with and complement the growing empirical evidence reported in scientific literature regarding the benefits of Augmented Reality (AR) in STEM learning. The findings of improvements in performance, motivation, and positive attitudes towards STEM are consistent with numerous previous studies such as those in Spain(7), Taiwan(8), and the United States(9), where AR demonstrated improvements in understanding, performance, and motivation in areas like chemistry, physics, and geometry. This supports the idea that AR can be a powerful tool to facilitate the understanding of complex concepts through visual and interactive representations.

However, this research makes novel contributions by comprehensively evaluating the impact of AR across multiple dimensions, including academic performance, motivation, attitudes, and conceptual understanding, providing a more holistic perspective than most previous studies focused on one or two specific aspects. Furthermore, the rigorous methodological approach, combining quantitative and qualitative methods, provides greater validity and depth by complementing numerical data with qualitative perspectives obtained through interviews, observations, and artifact analysis.

Nevertheless, a discrepancy is highlighted with previous studies(21,36) regarding technical challenges and cognitive load. Unlike the concerns expressed in those investigations, the findings of this study suggest that these challenges can be managed and mitigated through careful instructional design and strategic implementation. Although some minor technical difficulties were observed and the need for teacher training was recognized, these were not insurmountable impediments to the successful implementation of AR, indicating that with proper planning and a student-centered approach, the benefits can outweigh potential challenges.

In summary, this research contributes to the literature on the application of AR in STEM learning, providing new perspectives and solid empirical evidence on its impact in different contexts and specific areas. At the same time, it aligns with the general findings of previous studies, highlighting some discrepancies and novel contributions that enrich our understanding of this promising technology in the educational field.

CONCLUSIONS

The study's findings demonstrate a positive impact of Augmented Reality (AR) on STEM learning. Quantitative data showed substantial improvements in the academic performance of students who used AR compared to the control group that received traditional teaching. This suggests that AR facilitates the acquisition and

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understanding of complex concepts by providing visual and interactive representations.

Furthermore, the questionnaires revealed a positive effect of AR on motivation, favorable attitudes towards STEM, and the perceived usefulness of learned content, fostering greater engagement and enthusiasm for these disciplines. In line with these findings, qualitative data from interviews, observations, and artifact analysis complemented the quantitative findings, supporting AR's potential to create more engaging, interactive, and effective learning experiences in STEM, with increased participation, collaboration, and ability to visualize and apply complex concepts.

However, it is important to note that initial challenges were identified, such as the technical learning curve for teachers and the need for careful instructional design. These obstacles, although surmountable, highlight the importance of strategic planning, adequate teacher training, and a solid pedagogical approach to maximize AR's potential in the classroom.

In summary, the results validate the hypothesis that the integration of AR in STEM education can significantly improve academic performance, motivation, attitudes, and understanding of complex concepts. Therefore, these conclusions support the importance of continuing to explore and implement this innovative technology in these educational settings.

REFERENCES

1. Becker K, Park K. Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. Journal of STEM Education. 2011;12(5/6):23-37. https://www.jstem.org/jstem/index.php/JSTEM/article/view/1509

2. Zollman A. Learning for STEM Literacy: STEM Literacy for Learning. School Science and Mathematics. 2012;112(1):12-9. https://doi.org/10.1111/j.1949-8594.2012.00101.x

3. Núñez M, Quintero R, Chan ME, Vigier JC, Hugerat M. Integrated science concept learning through experiencing continuous processes in virtual labs. Journal of Science Education and Technology. 2008;17(6):587-603.

4. Potkonjak V, Gardner M, Callaghan V, Mattila P, Guetl C, Petrović VM, et al. Virtual laboratories for education in science, technology, and engineering: A review. Computers & Education. 2016;95:309-27. https://doi.org/10.1016/j.compedu.2016.02.002

5. Azuma RT. A survey of augmented reality. Presence: Teleoperators & Virtual Environments. 1997;6(4):355-85. https://doi.org/10.1162/pres.1997.6.4.355

6. Yuen S, Yaoyuneyong G, Johnson E. Augmented reality: An overview and five directions for AR in education. Journal of Educational Technology Development and Exchange. 2011;4(1):119-40. https://doi.org/10.18785/jetde.0401.10

7. Ibáñez MB, Delgado-Kloos C. Augmented reality for STEM learning: A systematic review. Computers & Education. 2018;123:109-23. https://doi.org/10.1016/j.compedu.2018.05.002

8. Chang YH, Wu HK, Hsu YS. Integrating augmented reality into multimedia book-based instruction: An exploratory study on students' learning performance and cognitive load. Journal of Research on Technology in Education. 2020;52(3):279-98.

9. Estapa A, Nadolny L. The effect of an augmented reality enhanced mathematics lesson on student achievement and motivation. Journal of STEM Education: Innovations and Research. 2015;16(3):40-8.

10. Radu I. Augmented reality in education: A meta-review and cross-media analysis. Personal and Ubiquitous Computing. 2014;18(6):1533-43. https://doi.org/10.1007/s00779-013-0747-y

11. Delgado FJ, Coas XA, Arza CV, Del Rey AM. Using augmented reality in high line construction education. Universal Access in the Information Society. 2015;14(2):251-68.

12. Zhang J, Sung YT, Hou HT, Chang KE. The development and evaluation of an augmented reality-based armillary sphere for astronomical observation instruction. Computers & Education. 2014;73:178-88.

13. Ibáñez MB, Di Serio A, Villarán D, Delgado-Kloos C. Experiencias de realidad aumentada en la educación:

Nuevas alternativas para la enseñanza. Madrid: Editorial Dykinson; 2014.

14. Singhal S, Bagga S, Goyal P, Saxena V. Augmented chemistry: Interactive education system. International Journal of Computer Applications. 2012;49(15):1-5.

15. Sommerauer P, Müller O. Augmented reality in informal learning environments: A field experiment in a mathematics exhibition. Computers & Education. 2014;79:59-68. https://doi.org/10.1016/j.compedu.2014.07.013

16. Bower M, Howe C, McCredie N, Robinson A, Grover D. Augmented Reality in education – cases, places and potentials. Educational Media International. 2014;51(1):1-15. https://doi.org/10.1080/09523987.2014.889400

17. Martín-Gutiérrez J, Fabiani P, Benesova W, Meneses MD, Mora CE. Augmented reality to promote collaborative and autonomous learning in higher education. Computers in Human Behavior. 2015;51:752-61. https://doi.org/10.1016/j.chb.2014.11.093

18. Yoon S, Elinich K, Wang J, Steinmeier C, Tucker S. Using augmented reality and knowledge-building scaffolds to improve learning in a science museum. International Journal of Computer-Supported Collaborative Learning. 2017;12(1):1-22.

19. Akçayır M, Akçayır G, Pektaş HM, Ocak MA. Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories. Computers in Human Behavior. 2016;57:334-42. https://doi.org/10.1016/j.chb.2015.12.054

20. Bujak KR, Radu I, Catrambone R, MacIntyre B, Zheng R, Golubski G. A psychological perspective on augmented reality in the mathematics classroom. Computers & Education. 2013;68:536-44. https://doi.org/10.1016/j.compedu.2013.02.017

21. Dunleavy M, Dede C, Mitchell R. Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. Journal of Science Education and Technology. 2009;18(1):7-22.

22. Barreira J, Bessa M, Pereira LC, Adão T, Peres E, Magalhães L. MOW: Augmented reality game to learn words in different languages: Case study: Learning English names of animals in elementary school. In: 2012 7th Iberian Conference on Information Systems and Technologies (CISTI). IEEE; 2012. p. 1-6.

23. Bujak KR, Radu I, Catrambone R, MacIntyre B, Zheng R, Golubski G. A psychological perspective on augmented reality in the mathematics classroom. Computers & Education. 2013;68:536-44. https://doi.org/10.1016/j.compedu.2013.02.017

24. Yoon S, Elinich K, Wang J, Steinmeier C, Tucker S. Using augmented reality and knowledge-building scaffolds to improve learning in a science museum. International Journal of Computer-Supported Collaborative Learning. 2017;12(1):1-22.

25. Ibáñez MB, Delgado-Kloos C. Augmented reality for STEM learning: A systematic review. Computers & Education. 2018;123:109-23. https://doi.org/10.1016/j.compedu.2018.05.002

26. Singhal S, Bagga S, Goyal P, Saxena V. Augmented chemistry: Interactive education system. International Journal of Computer Applications. 2012;49(15):1-5.

27. Chang YH, Wu HK, Hsu YS. Integrating augmented reality into multimedia book-based instruction: An exploratory study on students' learning performance and cognitive load. Journal of Research on Technology in Education. 2020;52(3):279-98.

28. Hewitt J, Pedretti E, Bencze L, Vaillancourt BD, Yoon S. New practices of science education through augmented reality: Students exploring optics concepts through new media and immersive experience design. Journal of Science Education and Technology. 2019;28(5):484-502.

29. Hsieh MC, Lin HCK. Virtual reality reactor auxiliary building system for education in radiation-applied programs. Computers & Education. 2017;109:73-90.

30.Martín-Gutiérrez J, Luís Saorín J, Contero M, Alcañiz M, Pérez-López DC, Ortega M. Design and validation of an augmented book for spatial abilities development in engineering students. Computers & Graphics. 2012;36(7):910-20. https://doi.org/10.1016/j.cag.2012.07.001

31.Webel S, Bockholt U, Engelke T, Gavish N, Olbrich M, Preusche C. An augmented reality training platform for assembly and maintenance skills. Robotics and Autonomous Systems. 2013;61(4):398-403. https://doi.org/10.1016/j.robot.2012.09.013

32.Bujak KR, Radu I, Catrambone R, MacIntyre B, Zheng R, Golubski G. A psychological perspective on augmented reality in the mathematics classroom. Computers & Education. 2013;68:536-44. https://doi.org/10.1016/j.compedu.2013.02.017

33.Estapa A, Nadolny L. The effect of an augmented reality enhanced mathematics lesson on student achievement and motivation. Journal of STEM Education: Innovations and Research. 2015;16(3):40-8.

34.Kaufmann H, Schmalstieg D. Mathematics and geometry education with collaborative augmented reality. Computers & Graphics. 2003;27(3):339-45. https://doi.org/10.1016/S0097-8493(03)00028-1

35.Kerawalla L, Luckin R, Seljeflot S, Woolard A. “Making it real”: Exploring the potential of augmented reality for teaching primary school science. Virtual Reality. 2006;10(3-4):163-74. https://doi.org/10.1007/s10055-006-0036-4

36.Wu HK, Lee SWY, Chang HY, Liang JC. Current status, opportunities and challenges of augmented reality in education. Computers & Education. 2013;62:41-9. https://doi.org/10.1016/j.compedu.2012.10.024

37.Bacca J, Baldiris S, Fabregat R, Graf S, Kinshuk. Augmented reality trends in education: A systematic review of research and applications. Educational Technology & Society. 2014;17(4):133-49.

38.Cuendet S, Bonnard Q, Do-Lenh S, Dillenbourg P. Designing augmented reality for the classroom. Computers & Education. 2013;68:557-69. https://doi.org/10.1016/j.compedu.2013.02.015

39.Wu HK, Lee SWY, Chang HY, Liang JC. Current status, opportunities and challenges of augmented reality in education. Computers & Education. 2013;62:41-9. https://doi.org/10.1016/j.compedu.2012.10.024

40.Akçayır M, Akçayır G. Advantages and challenges associated with augmented reality for education: A systematic review of the literature. Educational Research Review. 2017;20:1-11. https://doi.org/10.1016/j.edurev.2016.11.002

41.Cheng KH, Tsai CC. Affordances of augmented reality in science learning: Suggestions for future research. Journal of Science Education and Technology. 2013;22(4):449-62. https://doi.org/10.1007/s10956-012-9405-9

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