

Employing Mixed Reality to Develop Creative Thinking Skills among Graduate Physics Students

Dr. Rasha Abdel Hussein Sahib Abdel Hassan^{1*}

^{1*}Professor, College of Basic Education, University of Misan, Amarah, Iraq

E-mail: 1rasha.a.sahib@uomisan.edu.iq

ORCID: <https://orcid.org/0000-0003-1331-5290>

(Received 18 December 2025; Revised 24 January 2026, Accepted 09 February 2026; Available online 27 February 2026)

Abstract - Graduate physics students need to think creatively in order to provide answers to complex problems and advance science. Conventional education tends to focus on analytical abilities and does not give much chance to creativity. This paper discusses how mixed reality (MR) can be utilized to improve creative thinking among graduate physics students. A quasi-experimental design was employed in order to study forty graduate physics students (22-30 years old) studying at a public research university. Two groups were selected at random, including the experimental group (n=20), who were taught through the use of the Microsoft HoloLens 2 and the control group (n=20), who were taught with the use of the traditional lecture-laboratory instruction. The Torrance Tests of Creative Thinking (TTCT) were used to measure creative thinking, which includes fluency, flexibility, originality, and elaboration. The data regarding qualitative data were gathered by observation in the classroom, by student artifacts, and the reflective logs. In the overall creative thinking scores, the MR group had improved by +25% and the control group by +10%. It is worth noting that the MR group recorded significant gains in originality and elaboration. The qualitative data demonstrated that MR was creative due to the possibility of advanced visualization, efficient experimentation, and the exchange of ideas. This paper gives empirical data that MR can be effective in increasing creative thinking in graduate students of physics without affected learning of the content. The results indicate that MR is a useful pedagogical instrument to enhance creativity in STEM education, and it should be included into the advanced physics programs.

Keywords: Mixed Reality, Creative Thinking, Physics Education, Graduate Students, Immersive Learning

I. INTRODUCTION

As an essential part of innovation and complex problem-solving, creative thinking is widely considered a fundamental competence in education of science and engineering. Naturally, creativity is one of the five crucial skills needed to best utilize in future jobs based on the latest worldwide reports. Creativity allows physicists and other scientists to create new hypotheses, new experiments, and new ideas for difficult problems. Creativity itself is frequently described as the act of bringing something new and useful into existence, which suggests a double focus on novelty and utility. As such, developing this capacity in students has become one of the main priorities for modern education systems, since graduates able to think outside the box are more ready to face

unpredictable problems and promote technological advancement (Sinensis et al., 2025).

But nurturing creativity as part of a standard physics education is an additional challenge. But traditional methods of teaching are lectures, canned problem-solving techniques and validation labs that do not allow or even encourage open-ended exploratory work in student activities. Most graduate programs in physics are designed around a strong emphasis on content knowledge and skills. In fact, even for the brightest students, such a program becomes imprisoning because it restricts academic spaces that can be accessed through imaginative inquiry or collaborative creativity. Thus, ultimately prescribed thinking is inculcated among high-quality students who generate indexed-based excursions into any particular problem space (Yu & Wang, 2025). Pedagogical approaches-using technology-that allows for creativeness in cognitive processes apart from conceptual learning is what many teachers of physics have long been yearning.

It enables students to see inside augmented concepts or invisible concepts-in-place whereby theoretical models are brought into contact with real experience. In other words, it allows the students to view hidden aspects of the concept in which theoretical models are normally construed far from actual experiences and brings them close to actual experiences (Wongklang & Wipatsopakron, 2024). For example, AR has been used 3-D to represent electromagnetic fields or quantum phenomena so students could 'see' what usable looks like; AR allows the overlaying of simulations on real laboratory environments, thereby transforming a normal experiment into an exploratory sandbox where the student can easily check different parameters or 'what if' scenarios. Such freedom to play around in low-risk virtual settings might, as theorized, foster divergent thinking (many possible solutions)-a main component analyzed under creativity research. Earlier findings also triangulate high user engagement levels with extra time willingly spent fine-tuning ideas when students use AR/VR tools. For instance, Xiong et al., 2025 in a design task study participant using VR sketching tool continued elaborating creation (add new features to virtual model) long after minimally acceptable solution was reached compared peer using traditional tool.

Empirical evidence specifically linking MR to creativity in education is only now beginning to emerge (Prahani & Dawana, 2025). The conceptual premise is illustrated in Fig 1 mixed reality experience leads to greater student engagement and interactivity; hence, creative skills are activated at the cognitive level (imagination, flexible thinking, etc.) through upward cascading processes that can be construed as elements of creativity.

Researchers found significant improvements in pupils' scores on tests measuring their ability to think creatively when AR interventions were applied within traditional pedagogies aimed at achieving similar objectives through K-12 settings (Wibowo, 2023). For instance, found "great improvements" among gifted middle school students taught science using an Auras-based AR application with high effectiveness indicated by gain ratios from pre/post measures based on Torrance Tests of Creative Thinking (TTCT) used an AR-enhanced self-directed learning model and found significantly higher scores of creativities (and critical thinking) in the AR group on conceptual physics problems (Nisrina & Verawati, 2024). In design education, found that giving students a choice between AR or VR interface in a creative design task positively affected their creative output with results indicating a relationship between interface choice and type of creative ideas generated. Immersive and interactive media can indeed foster students' creativity by engaging them anew ways of learning and solving but most

research so far has either been with younger learners or involved explicitly creative disciplines such as design. There is scant research involving graduate-level science students operating at more advanced conceptual levels whose equally crucial-for- scientific-innovation creative development. (AlAli et al., 2025) see Fig 1

Previous studies have demonstrated that immersive technologies such as augmented reality (AR) and virtual reality (VR) can enhance creativity by improving visualization and learner engagement. AR allows digital overlays onto real environments, while VR provides fully virtual spaces detached from physical context. However, both approaches have limitations. AR often lacks depth of interaction, whereas VR may reduce contextual grounding and collaboration within real laboratory settings.

Mixed reality enables an interaction which is continuously available between physical and virtual elements. Mixed real preserves experimentation from the real world, which is so critical in physics education, while holographic objects in mixed reality dynamically respond to input from learners, thus allowing bidirectional interaction. This makes MR a more suitable technology for fostering creative experimentation and collaborative problem-solving in advanced physics contexts.

Conceptual Model

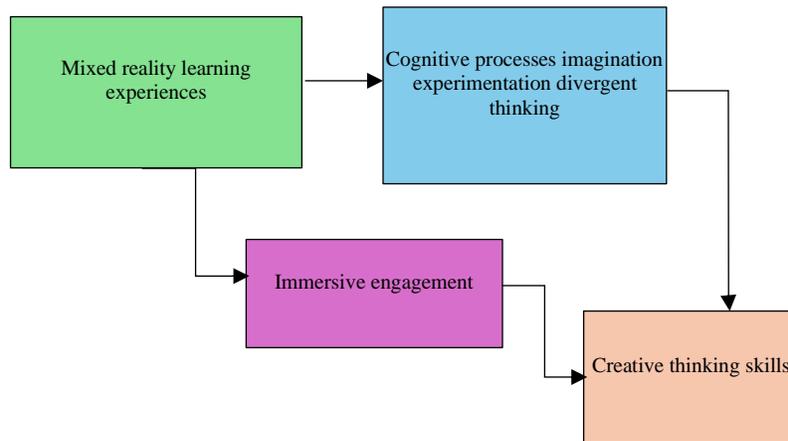


Fig. 1 Conceptual Model of Linking MR and Creative Thinking

This paper develops its conceptual model (Fig 1) based on previous works, wherein an effect relationship between mixed reality and creative thinking is assumed to be mediated by cognitive engagement. MR makes one attentive toward something through immersive visualization and interactive features; hence, a person becomes curious or tries to explore more. In such type of engaged process, creativity-related cognitive skills are activated for instance, divergent thinking, recombination of ideas, elaboration, (Fig. 1).

Seeing these trends and gaps, this study aims to provide new evidence on the role that mixed reality can play in higher education physics classes. The intended participants are graduate students of physics – normally technically very sound but needing further developmental training in creative

skills so they may be transformed into effective researchers/problem solvers. An MR technology application will be integrated into a graduate course intervention through which learning environments shall be established for exploration, curiosity, and innovative thinking beyond what is achievable using traditional methods (Faridi et al., 2021).

To sum up, this work aims at finding out how effective the use of mixed reality is in building creative thinking skills among graduate students of physics. The specific objectives are to determine if there is a higher gain in creative thinking (measured by the fluency, flexibility, originality, and elaboration of ideas) among graduate students learning through an MR-enhanced curriculum as compared to those

receiving traditional instruction and qualitative ways that MR technology influences their creative learning processes.

This study addresses a clear gap in physics education research concerning the development of creative thinking among graduate-level students using immersive technologies. While prior studies have focused primarily on school-level learners or design-oriented disciplines, this research provides empirical evidence on the role of mixed reality in fostering creativity within advanced physics education. The novelty of this work lies in examining creative thinking outcomes in a population with high prior analytical competence. The findings contribute empirically and methodologically to STEM education by demonstrating how mixed reality can be integrated into content-intensive graduate instruction to enhance creative cognitive processes without compromising conceptual learning.

Theoretical Foundation

The study is based on cognitive engagement theory and constructivist learning perspectives, which state that learning environments involving active participation, visualization, and exploration lay a basis for higher-order cognitive processes. Creative thinking defined as coming up with something new and useful is realized when learners are provided with opportunities for meaningful manipulation of concepts rather than being passive recipients hence developing full cognitive engagement.

Mixed reality aligns with these theories by providing real contextual settings, added with interactive virtual representations. MR externalizes complicated representations; thus, reducing the abstract cognitive load simultaneously promotes exploration, hypothesis testing, and reflection. Therefore, cognitive engagement is assumed to be intensified that will lead to creative thinking.

Rationale for Selecting Graduate Physics Students

Graduate physics students were chosen for the reason that they accommodate high levels of analytical competence but, however, always apply a rigid framework in solving problems due to traditional instruction. Creativity is an ingredient needed by advanced researchers in physics for generating hypotheses and experimental design together with solution finding across disciplines; hence this study assumes

creativity at graduate level has not been much explored particularly under technology-enhanced environments since such environment addresses a clear gap within research on physics education.

Study Contribution

- Offers empirical data about the impact of mixed reality (MR) on creative thinking in graduate students, a group that has received insufficient attention in the research on immersive learning.
- Both proposes and empirically attests to a conceptual model of connecting MR to cognitive engagement and creativity.
- Offers design-based evidence of incorporating MR in enhanced learning of physics without a loss in conceptual learning.

The paper is structured in the following way: Section I presents the theoretical background of the paper, the aim of the paper and the background of the paper. Section II elaborates the methodology, involving selection of the participants and MR intervention. Section III shows the findings or results in the form of quantitative and qualitative results and entails the discussion on findings and limitations. Section IV is the conclusion part of the paper.

II. METHODOLOGY

Participants and Context

In TABLE I, Participants were graduate physics students (master's level) at a research university. $N = 40$ (~22–30 years old). All had completed core undergraduate courses in physics; many were honing skills for career or further study requiring high-level problem-solving competence. They were randomly divided into two equal groups: Experimental (20) experiencing mixed reality interventions and Control (20) receiving the same content through conventional methods, over parallel instructional periods on advanced topics in quantum mechanics and electromagnetic theory-abstruse domains known both for conceptual difficulty when addressed via visualization and alternative approaches to instruction. Informed consent was obtained from all participants. The study has been approved by the institutional ethics committee (Yulkifli et al., 2025).

TABLE I CHARACTERISTICS OF THE STUDY SAMPLE

Variable	Experimental Group (n=20)	Control Group (n=20)
Degree level	Master's	Master's
Age range	22–30	22–30
Prior physics coursework	Completed core undergraduate physics	Completed core undergraduate physics
MR experience	None prior	None prior

Mixed Reality Intervention

The main MR device used was Microsoft HoloLens 2, a mixed reality head-mounted display. Each student in the experimental group had access to one HoloLens for at least a

two-hour session every week. The HoloLens's projected virtual three-dimensional content into real physical classroom and laboratory spaces dynamically and contextually relevant to the subject being taught or experimented with—for instance, while learning about

electromagnetic fields; students could see through their HoloLens dynamic field lines and force vectors superimposed around actual magnets and circuits on their lab bench. Holographic light waves and interactive polarization filters were superimposed on the real optical setup, allowing students to virtually adjust parameters-such as wavelength or filter orientation-and immediately observe results that would normally be impossible to see or require complex apparatus. Fig 2 shows an example of an MR-enhanced physics experiment from sessions: TABLE II illustrates the alignment between mixed reality learning activities and the targeted creative thinking skills addressed in this study. It includes MR activity such as the 3D visualization of abstract phenomena, parameter manipulation and simulation, open ended virtual experimentation and collaborative holographic modeling.

TABLE II RELATIONSHIP BETWEEN MR ACTIVITIES AND CREATIVE THINKING SKILLS

MR Activity	Targeted Creative Skill
3D Visualization Of Abstract Phenomena	Originality
Parameter Manipulation And Simulation	Flexibility
Open-Ended Virtual Experimentation	Fluency
Collaborative Holographic Modeling	Elaboration

The top image (a) shows the augmented HoloLens view with virtual indicators and real-time data overlay guiding the student, while the bottom image (b) presents the equivalent setup in the control condition with only physical equipment and paper-based instructions. The MR setup provided rich, visual, and interactive guidance- such as arrows, highlights, Laumann et al., 2024. Students were encouraged to "try out" ideas using the MR tools: for instance, to overlay hypothetical particles interacting and observe outcomes, or to manipulate a virtual parameter slider to see how a system responds. The MR app logged these interactions, but more importantly it created a playful sandbox where making mistakes was risk-free and reversing course was easy – features hypothesized to reduce inhibition and foster creativity. (Developed using Unity 3D and Vuforia, the MR application.). (Hidayati et al., 2023) see Fig 2

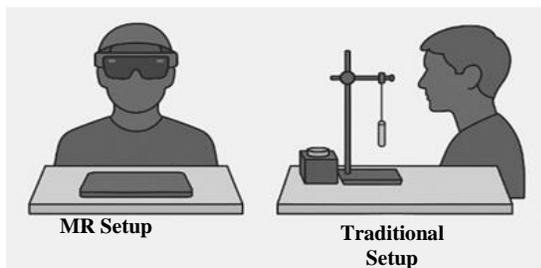


Fig. 2 Mixed Reality–Enhanced Physics Experiment Setup (a) A graduate student puts on a HoloLens MR headset. She sees holograms (vector diagrams and live graphs) over the real apparatus while guiding her interactively to perform an experiment on polarization optics. (b) The equivalent control

group experiment, using traditional equipment with printed instructions (Guaman-Quintanilla et al., 2023).

The MR content was carefully aligned with instructional objectives and incorporated principles of collaborative problem-solving (CPS) to further stimulate creativity. Following a model similar to that of Sinensis et al., 2025, each MR session was structured in phases: first, problem presentation – students were presented with an open-ended physics problem or scenario (e.g., “design a quantum experiment to measure a given phenomenon”) both verbally and through MR visualizations; next, interactive exploration – using the MR tools, students individually explored the problem space, formed hypotheses, or experimented with virtual models; then, collaborative discussion – students worked in small teams (mixing MR and non-MR participants for balance) to discuss their findings or ideas, often sharing what they visualized in MR with peers; finally, reflection – the whole class debriefed,

While approaches and solutions tend to be crafted in the ideate stage, MR technology expedited this phase by allowing students to literally share visual concepts and through partial shared metaphor space, where communication is placed on top of an augmented field of work (AlAli et al., 2025). The strategy rests on the premise that collaboration and visual communication can potentially improve bid creativity, as divergent viewpoints may serve to refine and embellish conceptualizations. In all these activities, the instructor served as a facilitator and not prescriptive: guiding students to observe carefully, asking What If? questions, and looking for other explanations when something was unexpected in the MR simulation.

Meanwhile topics for the control group were administered through traditional lecture-lab delivery. In this case, a classroom was conducted in a standard manner: a lecture using slides and figures from a textbook, followed by a series of lab activities using actual equipment with written instructions corresponding in content to the MR activities (but without any interactivity). This was done so that this group got equal practice in solving problems — for instance, they answered similar open-ended questions and carried out experiments, but they did so without augmented visualizations. As an ancillary tool for their work, Control students may have taken calculators or graph paper (Houzangbe et al., 2022).

Assessment of Creative Thinking

To assess the development of creative thinking skills in both groups, a combination of quantitative and qualitative assessment methods was applied: - Test on Creative Thinking Skills: All students were subjected to a standardized testing regime as a pre-test (prior to any interventions) and post-test (after six weeks). The test instrument was adapted from well-validated tools within creativity research comprising components from both the Torrance Tests of Creative Thinking (TTCT) and domain-specific tasks for assessing creative problem solving. Some example items included “List

as many uses or solutions for a given physics concept/problem] as you can” to measure idea fluency, with scientific-context originality-and-elaboration questions such as “Describe a unique experiment to investigate phenomenon X.” Four main indicators formed the basis for scoring:

1. **Fluency** – the number of relevant ideas or solutions generated.
2. **Flexibility** – the diversity of categories or approaches among the ideas.
3. **Originality** – the novelty or uniqueness of the ideas (compared to peers).
4. **Elaboration** – the amount of detail and development of the ideas (Hassan, 2024).

A total creativity score was then generated collectively from each indicator, which was rated individually on a pre-existing rubric (i.e., the scale). Tests were scored by independent raters (blinded to group) with high inter-rater reliability (Cohen's $\kappa > 0.85$). This type of approach stays true to the classic definition of creativity (novelty + usefulness) and rewards ideas, not by count but by type and degree. The two groups appeared balanced on creative thinking (overall scores were not significantly different in pre-test, $p > 0.5$).

- **Qualitative Observations and Artifacts.** In the MR group, the HoloLens application itself took screenshots and recorded video clips (with students' permission) of interesting moments—for example, a student testing an idea by manipulating a hologram in some unusual way. Lab notebooks in both groups prompted students to jot down any “new idea” or approach they tried; brief reflections on challenges encountered and how these were overcome were also encouraged. These later became available for analysis as qualitative indicators/markers/descriptors/evidence-of creative thinking such as remote association between disparate concepts (Batlolona & Diantoro, 2023).
- **Survey on Experience:** Students completed a short survey on their learning experience after the post-test. Items in the experimental group's survey measured effects on thinking process by MR tools, for example, “The MR visualizations helped me come up with ideas. This provided supplementary evidence on student perceptions of whether MR influenced their creativity or motivation (Sharma & Soederberg, 2020).

Data Analysis

This study applied appropriate statistical analysis for the pre-post two-group experimental design. A mixed ANOVA was conducted with Time (Pre, Post) as a within-subject factor and Group (MR, Control) as a between-subject factor to test whether there was an interaction effect in terms of different changes over time between groups in creativity scores. Independent sample t-tests on gain scores (post-pre) for overall creativity score and each of the four indicators were also carried out to determine which aspects showed

significant differences at $\alpha = 0.05$ significance level all tests. Qualitative data comprising observation notes, student reflections etc. were analyzed thematically (Demircioglu et al., 2023).

By combining these methods, the study not only measures if MR improves creative thinking outcomes, but also sheds light on why and how MR might influence students' creativity. The methodological triangulation enhances the validity of conclusions about mixed reality's role in developing creative thinking skills among graduate physics students.

III. RESULTS AND DISCUSSION

Quantitative Outcomes

By the termination of the intervention, an apparent increment in the performance of creative thinking within the experimental group as compared to the control group was noticed. TABLE III contains a summary of pre-and post-scores on creative thinking for both groups, with sub-scores on fluency, flexibility, originality, and elaboration. Both groups commenced at about mid-range comparable scores on scale but their paths were quite distinct. The control group showed a slight improvement after traditional instruction—for example its average score on fluency increased slightly because students had more practice in problem-solving-but this gain is not significant statistically in most categories ($p > 0.05$). On the other hand, [Mixed Reality]MR Group has high positive increments across all indicators of creativity. Time \times Group interaction effect ($F_{1,38} = 8.75$, $p = 0.005$) between: MR group's overall creativity score jumped by about +25% from pre to post (increase from mean 50.3 to 63.0 on 100-point normalized scale, $SD \approx 10$) while control group increased by just +10% (49.5 to 54.5, $SD \approx 9$). This clearly supports the main hypothesis of this study that students who learn with mixed reality enhance their creativity more than those who do not because there was a statistically significant difference between both classes over time in favor of the MR-integrated class; i.e., greater improvement in creative thinking for mixed reality integrated class than traditional class. (Ali & Al-Mutairi, 2021) see Fig 3

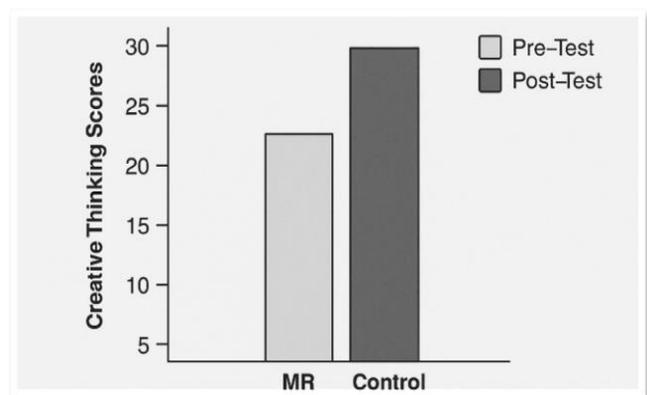


Fig. 3 Creative Thinking Scores: Pre- and Post-Test Comparison

As shown in Fig 3, the MR group began at a baseline similar to that of the control group and ended at a comparable final score but surpassed the improvement of the control group by a wide margin. Breaking down by sub-skills: Fluency (number of ideas) approximately doubled on average in the MR group (mean ideas listed increased from 6 to 12, for example, on one prompt), while a smaller increase was observed in the control group (~6 to 8 ideas). A larger increase was also observed in flexibility (different categories of ideas) under the MR condition, with students proposing a wider range of approaches to each problem after having gone through the MR experience (for instance, combining knowledge from optics and thermodynamics to generate interdisciplinary solutions-seldom seen at pre-test). One of the most striking differences was in the originality scores of the MR group. Many MR students came up with at least one or two truly novel ideas that none of their peers (in either group) had, whereas at pre-test their ideas were mostly standard. This led to significantly higher post-test originality ratings for MR students (by rubric, ~30% higher than control on average; $t(38) = 3.1, p < 0.01$). Elaboration (level of detail) also improved; MR students' solutions tended to be more fleshed out, often including diagrams or steps that they had essentially "tried" in the virtual environment and thus

could describe clearly. A paired t-test within the MR group confirmed that improvements on all four indicators were statistically significant ($p < 0.001$ in each case), whereas the control group's gains were only significant for fluency ($p < 0.05$) and not for the other indicators. The strong performance of the MR group is consistent with previous findings on AR/VR in education that report creativity and innovation skills to be improved after immersive interventions. The magnitude of effect observed here-an approximately 0.8 standard deviation improvement detected between creativity scores over control within an MR group-recent meta-analysis reported overall effect size~0.82 for student creativity impacted by immersive technology. Literature convergence places a high possibility that this claim is valid: yes, the MR intervention has stimulated creative thinking. See TABLE III

Pre-test and Post-test creative thinking scores (mean \pm SD) for the Control group versus the Mixed Reality (MR) group. The MR group demonstrated a significantly larger increase in total creativity scores from pre to post, as well as higher post-test scores, compared to the Control group ($p < 0.01$). Specific sub-skills made large gains under the MR intervention. These included originality and elaboration are shown in TABLE III

TABLE III PRE- AND POST-TEST CREATIVE THINKING SCORES FOR CONTROL AND MIXED REALITY GROUPS

Creative Thinking Skill	Group	Pre-Test Mean (SD)	Post-Test Mean (SD)	Gain
Fluency	Control	12.4 (3.1)	15.1 (3.4)	+2.7
	MR	12.6 (3.0)	20.3 (3.8)	+7.7
Flexibility	Control	10.8 (2.9)	12.2 (3.1)	+1.4
	MR	11.0 (2.8)	17.6 (3.5)	+6.6
Originality	Control	9.7 (2.6)	10.9 (2.8)	+1.2
	MR	9.9 (2.7)	15.8 (3.2)	+5.9
Elaboration	Control	11.6 (2.8)	13.0 (3.0)	+1.4
	MR	11.8 (2.9)	18.4 (3.6)	+6.6
Total Creativity Score	Control	49.5 (9.1)	54.5 (9.4)	+5.0
	MR	50.3 (9.3)	63.0 (10.1)	+12.7

Note. Values are presented as mean scores with standard deviations in parentheses. Gain represents the difference between post-test and pre-test scores. The Mixed Reality (MR) group demonstrated significantly higher gains across all creativity dimensions compared to the control group ($p < 0.01$)

There were no pre-existing differences or outside factors to check. Both groups had almost identical scores on a physics conceptual post-test (content knowledge), which means the MR group did not sacrifice creativity for learning physical content; if anything, the MR group had a slightly higher conceptual gain that was not statistically significant. This result is in line with findings from other research showing that immersive learning can improve understanding when cognitive load does not exceed what students can handle. In this case, an interesting observation was that many students seemed to channel their creative solutions through deeper understandings (e.g., "seeing the field lines in 3D helped me think of a new way to shape the magnet"). There was no significant difference in self-reported study time or motivation between groups before the intervention. Mean values of both variables are slightly higher for the MR group but this difference is not statistically significant, $p > .05$

(TABLE II). However, after the intervention, MR students reported higher enjoyment and engagement.

Qualitative Insights into Creative Processes

Thematic analysis was conducted on the qualitative data in a six-step process: familiarization, coding, generating themes, reviewing themes, defining and naming themes, and producing the report. The data consisted of observation notes, student reflections, learning artifacts, and records of interactions within MR. Two researchers independently coded the data inductively. Initial codes were compared between two coders and reconciled through discussion to arrive at final consensus codes. Inter-rater reliability was high (Cohen's $\kappa = 0.85$), indicating strong agreement between raters. All discrepancies were resolved through discussion and consensus. Themes emerged from clustering related codes that represented repeated patterns of creative behavior (e.g., exploratory experimentation idea recombination collaborative elaboration) across different groups Visual conceptual maps annotated screenshots from within MR used assist interpretation reduce reliance purely descriptive narrative

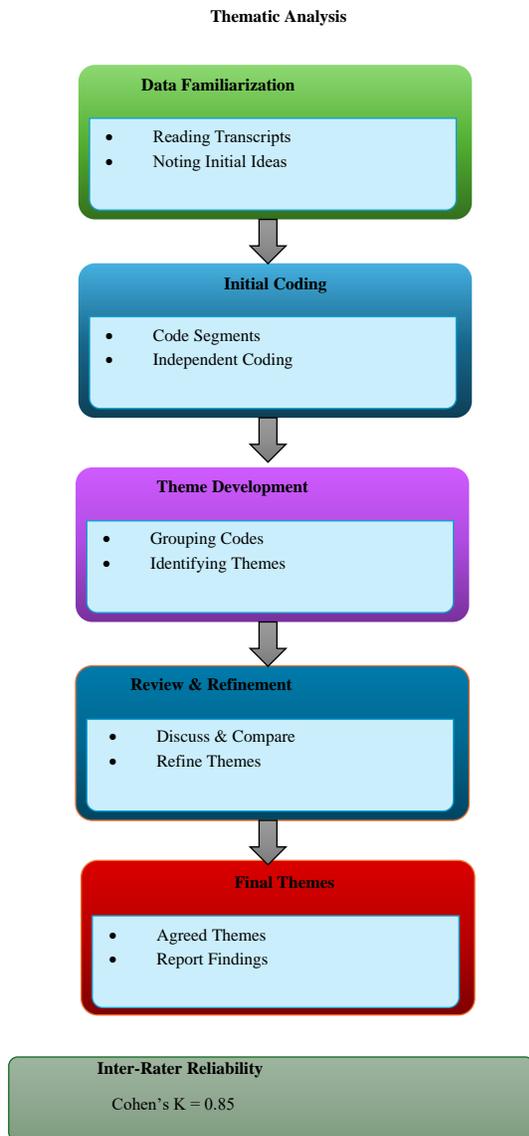


Fig. 4 Thematic Analysis Process Flowchart

The thematic analysis (Fig 4) is a technique of analyzing qualitative data and this flowchart demonstrates the procedure step by step. It starts with the step of Data Familiarization in which transcripts are read and preliminary ideas recorded. It follows the step of initial Coding, Theme Development and Review and Refinement wherein codes are clusterized, themes are discovered and developed. The final step is the Final Themes in which agreed themes are reported. There is an inter-rater reliability indicated by the Cohens Kappa of 0.85 which shows a high level of agreement among coders. The flowchart helps in the visualization of the narrative of the thematic analysis, which makes comprehending the main stages and their connections easier.

Comparison with Literature and Implications

These results not only endorse but also broaden the current rapidly accumulating body of work that demonstrates that immersive technologies can move creativity in education

well beyond traditional limits. The size of creative gains observed here (MR showing an approximately double gain over control methods) is very much in the ranges observed in meta-analytic work on overall effect strengths for immersive technology interventions on creativity. Xiong et al., 2025 finally found by a synthesis combining studies 2012–2023 that when coupled with more student-centered pedagogical methods, VR/AR often enhance student creativity and with a large effect size (2025). This study implemented MR through an inquiry-based group learning activity, thereby probably making its influence even stronger. They emphasized the necessity for active pedagogy and indeed own observation was students were first wowed by MR but real ‘breakthroughs’ emerged during guided reflection-in-action as teamwork unfolded. That aligns with the notion of technology as tools—its use within a context. More practical is that handing out MR devices does not automatically mean instructors should integrate them into well-structured learning activities, which involve exploration and creativity in answering questions. For instance, many participants noted that they could ‘feel’ certain effects—for example quantum tunneling or electromagnetic fields—through MR which previously they only understood analytically; this feeling experience seems to activate another mode of thought (more intuitive and imaginative) in analytically oriented students. The same study found multiple modes (visual/kinesthetic), as well as affective responses engaged, this goes a long way to prove the possibility of what education experts have argued should be made a mandate in developing wholistic expertise-creativity can and should be embedded within higher education. Ours is an existence proof that a specific, targeted intervention in creativity within a content-heavy domain such as physics can result in measurable improvement of creativity with no compromise on learning of content.

From a cognitive perspective, mixed reality provided immediate feedback and also offloaded some cognitive tasks, such as visualizing complex three-dimensional fields to the technology itself. Therefore, more free working memory could be available for creative thinking within MR than with traditional problem-solving methods that maintain high total cognitive load levels on students’ working memories. Students were not struggling to imagine what an abstract concept looks like—they could see it—and thus could spend more effort on. Found that AR reduces extraneous This finding added support to that version of the story: MR and control students ended up with comparable mastery, but meanwhile, MR students found spare mental energy to “play” with ideas. More explicitly guided by MR’s interactivity, their path might be conceived as scaffolded in a Vygotskian sense through which they travel creatively at a higher zone of proximal development—aspect future research can fruitfully investigate.

One more MR pair went totally interdisciplinary and suggested using the quantum Zeeman effect on atomic spectra (splitting of lines) and observing spectral lines with an AR spectroscope, which was exceptionally creative. Such

solutions were rarely seen in regular classes. Though purely anecdotal, this underlines not only the number but also the different nature-character-of ideas that MR can inspire: often cross-conceptual, incorporating visualization as a part of solution strategy.

Limitations

Despite the positive findings, several limitations should be acknowledged. First, the study relied on a relatively small sample from a single institution, which limits generalizability. Second, the use of head-mounted MR devices involves accessibility constraints related to cost, availability, and physical comfort. Some students required additional time to adapt to the MR interface, indicating a learning curve that may affect early engagement.

Technical constraints such as limited field of view, battery life, and occasional system latency may also influence learning experiences. Furthermore, although efforts were made to minimize novelty effects, the possibility that initial enthusiasm contributed to increased engagement cannot be fully excluded. Future research should employ longitudinal designs to examine sustained creative development beyond short-term interventions.

IV. CONCLUSION

To sum up, this research offers empirical data regarding how mixed reality (MR) affects the development of creative thinking among graduate physics learners. The study showed that MR-enhanced students showed a great improvement in creative thinking in all the dimensions of fluency, flexibility, originality and elaboration, than students in the control group who were taught through conventional means. Statistical manipulation indicated that there was an enhancement in the creativity scores in the MR group by 25 %, which was significantly better than the 10 % enhancement in the control group ($p < 0.01$). The findings highlight the efficiency of MR as a means of creative problem-solving and interdisciplinary thinking in problem-based learning, such as physics. Another conceptual model that was presented in the study was the connection between MR and cognitive engagement and creativity which offered a framework of understanding how immersive technologies can be used to increase the creative abilities of STEM education (Faridi et al., 2021). Moreover, the results indicate that MR could be incorporated into the superior physics curricula without affecting conceptual learning, and it is a useful pedagogic instrument. Long-term consequences of MR on creative thinking may be examined in future studies, taking into account such aspects as the ability to remain engaged and apply the skills outside of the classroom. Also, the research may seek to examine how MR can be used across other fields of science and across various levels of education and the availability and cost of MR technologies to wider educational use.

REFERENCES

- [1] AlAli, R., Wardat, Y., Aboud, Y. Z., & Alhayek, K. A. (2025). The effectiveness of using augmented reality technology in science education to enhance creative thinking skills among gifted eighth-grade students. *EURASIA Journal of Mathematics, Science and Technology Education*, 21(6), em2644. <https://doi.org/10.29333/ejmste/16416>
- [2] Ali, E., & Al-Mutairi, W. A. (2021). The Use of Reciprocal Teaching Strategies in Developing Mental Visualization among Kindergarten Department Students in the Subject of Theater for Young Audience. *Rigeo*, 11(4).
- [3] Batlolona, J. R., & Diantoro, M. (2023). Mental models and creative thinking skills in students' physics learning. *Creativity studies*, 16(2), 433-447. <https://doi.org/10.3846/cs.2023.14743>
- [4] Demircioglu, T., Karakus, M., & Ucar, S. (2023). Developing students' critical thinking skills and argumentation abilities through augmented reality-based argumentation activities in science classes. *Science & Education*, 32(4), 1165-1195.
- [5] Faridi, H., Tuli, N., Mantri, A., Singh, G., & Gargrish, S. (2021). A framework utilizing augmented reality to improve critical thinking ability and learning gain of the students in Physics. *Computer Applications in Engineering Education*, 29(1), 258-273. <https://doi.org/10.1002/cae.22342>
- [6] Guaman-Quintanilla, S., Everaert, P., Chiluliza, K., & Valcke, M. (2023). Impact of design thinking in higher education: a multi-actor perspective on problem solving and creativity. *International Journal of Technology and Design Education*, 33(1), 217-240.
- [7] Hassan, R. A. H. S. A. (2024). Effectiveness of Web-Based Cognitive Apprenticeship in Learning Classical Mechanics and Enhancing E-Learning Confidence in Physics Students in Iraq. *Kuram ve Uygulamada Egitim Bilimleri*, 24(2), 76-87.
- [8] Hidayati, N., Fitriani, A., Saputri, W., & Ferazona, S. (2023). Exploring university students' creative thinking through digital mind maps. *Journal of Turkish Science Education*, 20(1), 119-135. <https://doi.org/10.36681/tused.2023.007>
- [9] Houzangbe, S., Masson, D., Fleury, S., Gómez Jáuregui, D. A., Legardeur, J., Richir, S., & Couture, N. (2022). Is virtual reality the solution? A comparison between 3D and 2D creative sketching tools in the early design process. *Frontiers in Virtual Reality*, 3, 958223. <https://doi.org/10.3389/fvrvir.2022.958223>
- [10] Laumann, D., Schlummer, P., Abazi, A., Borkamp, R., Laströer, J., Pernice, W., ... & Heusler, S. (2024). Analyzing the effective use of augmented reality glasses in university physics laboratory courses for the example topic of optical polarization. *Journal of Science Education and Technology*, 33(5), 668-685.
- [11] Nisrina, N., & Verawati, N. N. S. P. (2024). Impact of Blended Learning on Students' Creative Thinking Skills in Wave and Optics Course. *Lensa: Jurnal Kependidikan Fisika*, 12(2), 287-296. <https://doi.org/10.33394/j-lkf.v12i2.13748>
- [12] Prahani, B. K., & Dawana, I. R. (2025). Exploring the potential of technology in physics education: current research and innovation trends to support 21st century skills. *Перспективы науки и образования*, (1 (73)), 349-361. <https://doi.org/10.32744/pse.2025.1.23>
- [13] Sharma, S., & Soederberg, S. (2020). Redesigning the business of development: the case of the World Economic Forum and global risk management. *Review of International Political Economy*, 27(4), 828-854. <https://doi.org/10.1080/09692290.2019.1640125>
- [14] Sinensis, A. R., Firdaus, T., Rizki, U., & Widayanti. (2025). Augmented reality-integrated teaching materials on modern physics: Enhancing creativity of prospective physics teachers through collaborative problem-solving. *International Journal of Information and Education Technology*, 15(9), 1915-1922. <https://doi.org/10.18178/ijiet.2025.15.9.2392>
- [15] Wibowo, F. C. (2023). Effects of Augmented Reality Integration (ARI) Based Model Physics Independent Learning (MPIL) for Facilitating 21st-Century Skills (21-Cs). *Journal of Technology and Science Education*, 13(1), 178-192. <https://doi.org/10.3926/jotse.1800>

- [16] Wongklang, P., & Wipatsopakron, J. (2024). The Development of Problem-Based Mobile Augmented Reality Application to Enhance Creative Problem-Solving Skills for Undergraduate Students. *International Journal of Interactive Mobile Technologies*, 18(7). <https://doi.org/10.3991/ijim.v18i07.42261>
- [17] Xiong, J., Wen, J., Han, X., Cui, W., Pei, G., & Tao, Z. (2025). Effect of Immersive Technology on Students' Creativity: A Meta-Analysis. *SAGE Open*, 15(3), 21582440251361624. <https://doi.org/10.1177/21582440251361624>
- [18] Yu, H., & Wang, J. (2025). Enhancing college students' creativity through virtual reality technology: a systematic literature review. *Humanities and Social Sciences Communications*, 12(1), 1-14.
- [19] Yulkifli, Y., Hariyanto, D., Suprpto, N., Hakim, S. R., Mufit, F., Dhanil, M., & Novitra, F. (2025). The Impact of Virtual Reality on Creative Thinking Skills and Self-Efficacy in Learning Rotational Dynamics. *International Journal of Information and Education Technology*, 15(6), 1302–1311. <https://doi.org/10.18178/ijiet.2025.15.6.2332>