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The Impact of Immersive Virtual Reality Simulations on Student Engagement and Emotional Resilience in Climate Change Education

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Abstract

Climate change education is indispensable in higher education institutions due to the need for scientific knowledge, readiness, and awareness in order to cope with escalating environmental problems. The country of Uzbekistan faces various environmental problems, including water shortage, desertification, heat stress, and vulnerability in agriculture, making sustainability education extremely important. In this study, the effect of the use of virtual reality (VR) simulations in terms of increasing the level of emotional resilience and effective climate change education in Uzbek universities was analyzed. A quasi-experimental method was used by conducting a pretest-posttest experiment in two groups, where one group learned about climate change using VR simulations and the other using traditional teaching methods. The VR modules depicted the climate scenarios, including melting glaciers, desertification, flooding in the city areas, heat waves, loss of biodiversity, and shortage of water. It was discovered that in the experimental group, there was an increase in the improvement of the students' engagement level from 3.12 to 4.26, while in the control group, an increase in engagement levels was observed from 3.08 to 3.46. Emotional resilience also increased significantly for the experimental group, with changes from 2.94 to 4.01, while for the control group, from 2.91 to 3.28. There were also improvements in the climate knowledge and level of learning satisfaction.

Keywords: Immersive Virtual Reality, Climate Change Education, Student Engagement, Emotional Resilience, Sustainability Learning, Climate Anxiety, Uzbek Higher Education.

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Introduction

Education about climate change has been increasingly recognized as a key component of higher education, as students require scientific knowledge, environmental awareness, and skills in making decisions related to addressing the global challenges that are related to climate change. In particular, in developing nations and those that are vulnerable to climate change, such as Uzbekistan, climate change has implications for the availability of water resources, agricultural practices, human health, biodiversity, and sustainable development in general. In light of that, the role of universities should include providing students not only with theoretical knowledge related to climate change but also connecting this kind of knowledge to real-world environmental problems (Avcu & Yaman, 2025). Nonetheless, traditional teaching strategies rely heavily on lectures, textbook explanations, illustrations in terms of diagrams and tables, as well as statistical data. While these approaches can be used to provide some basic information, climate change can still be perceived by students as being distant from their reality and emotionally detached.

Immersive VR simulations present a fresh chance to enhance climate change education through experience-based, real-life learning scenarios (Zhang & Song, 2022). Through VR technologies, students were able to virtually see situations related to climate change, such as the melting of glaciers, desertification, urban flooding, heat stress, water scarcity, and ecosystem degradation (Llanos-Ruiz et al., 2025). These types of scenarios have the potential to bring climate change closer to students through visual experiences. While traditional educational practices do not allow for such experiences, VR simulations engaged and motivated students to learn better about climate change. At the same time, these simulations assisted students in developing emotional resilience since they gave them the chance to face the dangers posed by climate change without feeling powerless or scared. However, research has been done on the impacts of immersive VR simulations on student engagement and emotional resilience in climate change education. Thus, the purpose of this study is to assess the effects of immersive VR simulations on student engagement and emotional resilience during climate change education. This study makes an important contribution to research by introducing VR-based climate education as a novel learning strategy in the context of sustainability education among Uzbek university students.

This paper is sequentially structured. Section I addresses the significance of climate change education, limitations associated with conventional education, and how immersive virtual reality is helpful to enhance student engagement and emotional resilience. Section II provides an overview of the existing literature on climate change education, sustainability in VR environments, student engagement, and emotional resilience, as well as describes the research gap, research questions/hypotheses/objectives, and previous studies' findings. Section III discusses the methodology of the study, including its quasi-experimental design, the characteristics of the sample involved, the intervention, the variables measured, the instruments, and the statistics used. Section IV presents research findings and discussion, covering demographic information of students, comparisons between pretest and posttest findings, and testing of hypotheses related to the impact of VR learning on student behavior and academic performance. Section V concludes.

Literature Review

Climate change education has become a crucial part of contemporary education since there is a necessity to teach students about environmental risks, climate adaptation and mitigation measures, and responsibilities for sustainable development. Traditionally, climate change education relied heavily on lectures, textbooks, statistical reports, and documentary representations. Despite the effectiveness of these methods to teach the scientific foundations of climate change, they may not necessarily ensure deep personal engagement in the process of learning. In most cases, climate change is considered to be a faraway phenomenon that cannot be experienced by students. For this reason, current educational research stresses the importance of experiential learning when learners are involved in the process of observing, experiencing, reflecting, and applying knowledge gained to practical life situations. Simulated learning and digital pedagogy have proved to be efficient methods of promoting climate literacy, critical thinking skills, and climate change awareness in students (Suryati et al., 2025; Tabbu et al., 2024; Na et al., 2026).

IVR is considered an effective approach to teaching sciences, environments, and sustainability since it enables students to go through a number of climate-related situations within a digital reality, including sea-level rise, environmental degradation, climate risks, loss of biodiversity, and sustainable development projects. As demonstrated in previous research (Markowitz et al., 2018), IVR field trips can be used as a tool to promote learning about climate change due to the ability of VR to increase the level of interactivity and make the issue much clearer. Furthermore, virtual field trips may enhance immersive learning related to climate change, provided that VR is integrated into lessons adequately (Petersen et al., 2020). Similar findings indicate that using VR simulations is helpful to foster interaction, visualization, and comprehension skills while learning about environmental science (Cho & Park, 2023; Fauville et al., 2020). Some

of the latest studies suggest that VR holds promise for educating about climate change because it can integrate scientific facts, emotions, and visuals (Tisoglu et al., 2025). The use of VR has been associated with SDG 13, sustainability consciousness, environmental attitudes, and community participation (AlQallaf et al., 2024; Carmona-Galindo et al., 2025; Chiu & Lien, 2025).

Student engagement and emotional resilience are two essential educational outcomes in climate change education. Student engagement involves the focus and participation of students in learning. An empirical study indicated that the use of VR can increase classroom engagement through immersion, interaction, and learner-focused learning (Lin et al., 2024). In the context of environmental education, the issue of emotional response is also relevant since climate change issues might generate feelings of fear, helplessness, or emotional distancing in students. Consequently, climate change education must not only provide information, but it also has to help students build resilience, hope, responsibility, and confidence to address the challenges of environmental degradation (Zhongyao et al., 2024). Additional studies highlight the importance of emotion in education for sustainable development using virtual reality technology, while linking game-based environmental learning with student engagement and resilience (Xu et al., 2026; Stone et al., 2021). The research on hazard mitigation, sea level rise planning, and community resilience shows the benefits of immersive visualization in terms of risk awareness and increased meaningful participation (Ismael, 2024; Stone et al., 2021; Calil et al., 2021).

Nevertheless, a significant research gap can be found in the current academic literature. For instance, the majority of academic papers devoted to climate change education using VR technology consider issues of knowledge, awareness, attitude, or concept acquisition as primary outcomes. Furthermore, few studies have examined the effect of VR simulation on both student engagement and resilience simultaneously. Moreover, not many studies were carried out on this problem within the scope of Uzbek universities, which is highly important for Uzbek higher education since there are several environmental issues in the region, including water shortage, desertification, vulnerability of agriculture, and sustainability. Hence, the present study aims to explore the effect of immersive VR simulations on the engagement and emotional resilience of Uzbek college students during climate change education.

Research Objectives

1. The impact of VR simulations on student engagement in climate change education.
2. The impact of VR simulations on climate change learning in enhancing the emotional resilience of students.
3. Comparison between the learning responses of students subjected to VR simulations and those taught using traditional classroom teaching methods.
4. The relationship between student engagement, emotional resilience, and the results of learning about climate change.

Research Hypotheses

Considering the stated objectives and the literature review, the hypotheses for this research will be:

H1: Immersive VR simulations have a significant effect on increasing student engagement in climate change learning.

H2: Immersive VR simulations have a significant impact on increasing emotional resilience among students involved in climate learning scenarios.

H3: Climate change learning through VR simulations results in significantly better learning outcomes compared to traditional classroom learning.

H4: There is a positive relationship between student engagement and emotional resilience in climate change learning. The stated hypotheses would aid in assessing whether VR simulation-based climate learning makes a difference in terms of improving not only learning but also the behavioral/emotional response of students toward climate issues.

Methodology

Research Design

The design that was utilized in this research is that of the quasi-experimental research. It investigated how the use of immersive Virtual Reality simulation influences students' engagement and emotional resilience levels, as well as their climate change learning outcomes. A pre- and post-test control group design was used, as a comparison was made of the learning outcomes of two different sets of participants, each receiving education on climate change. While the participants from one group get climate change education using immersive VR simulation, those from another one

receive information about climate change using conventional ways, including lectures, slide presentations, books, and discussions. Prior to the educational program, all participants underwent pre-testing in order to establish their initial state regarding climate change knowledge, engagement, and emotional resilience.

Participants and Study Context

Participants of this study were selected among undergraduate students at selected universities in Uzbekistan. They came from various majors such as environmental science, education, engineering, social sciences, and general science majors due to the importance of climate change education for several disciplines. A total of 120 undergraduate students participated in this study, evenly distributed between the experimental group ($n = 60$) and the control group ($n = 60$). Selection of participants followed general selection criteria, including participation in an undergraduate degree, readiness for participation, having basic IT skills, and a lack of previous experience in intensive VR training on climate change. The experiment did not involve participants who suffered from severe motion sickness because of their medical condition and the discomfort in using VR headsets. The experiment was conducted in Uzbekistan, as climate issues in the region include water shortage, desertification, heat stress, and agricultural vulnerability.

VR Simulation-Based Learning Intervention

The experimental group underwent an engaging VR-based climate change learning program. This program involved using digital simulation modules that depicted various climate change scenarios, such as glacier meltdown, desertification, urban flooding, heat waves, loss of biodiversity, and water shortages. The modules were tailored in such a way that they permitted students to see the effects of climate change in a three-dimensional world. This program took four weeks, where each week, there was one VR-based learning session that took about 45–60 minutes. These sessions involved orienting learners to the VR process, conducting a VR session, discussing what happened in the session, and reflecting on it. In the VR sessions, students explored climate scenarios, saw changes happening in the environment, understood the causes and effects of such events, and reacted to various learning prompts. Following each session, learners reflected in short discussions on the climate issues in Uzbekistan and sustainable development objectives globally.

Variables of the Study

The independent variable of the research will be the use of an immersive virtual reality simulation-based intervention for learning about climate change. It means that the use of interactive technology of VR to learn climate change topics will serve as the independent variable. On the other hand, the dependent variables in the research will be student engagement, emotional resilience, and climate change learning outcomes. Student engagement implies the level of students' engagement, attention, and involvement while learning climate change topics. Emotional resilience involves the ability of the students to comprehend and assess the risk of climate change topics without feeling fear or hopelessness, and to cultivate optimism.

Data Collection Tools

Information is gathered through the use of standardized pre-test and post-test tools. The student engagement scale is employed for assessing the extent of behavioral, emotional, and cognitive engagement exhibited by the learners during the learning process. A measure of emotional resilience is utilized to gauge confidence levels, ability to cope, emotional stability, and reaction toward the climate change challenges. A measure of climate change knowledge is employed for evaluating student awareness concerning climate change, its effects, adaptation, mitigation strategies, and sustainability practices. Also, a feedback questionnaire is provided to the experimental group for obtaining students' views on virtual reality-based learning, such as usability, realism, interest, emotional response, and value of learning.

Data Analysis Methods

The data were analyzed through the application of quantitative statistical tests. Mean, standard deviation, frequency, and percentages are descriptive statistics used to analyze the demographic profile and responses obtained. A paired sample t-test was used to analyze the differences between the pre-test and post-test scores within each group. An independent sample t-test was employed to analyze the scores of post-tests for the experimental group and the control group. Correlation was tested in order to determine the association between student engagement, emotional resilience, and learning outcomes on climate change. The regression test was used to find out if there was a predictive relationship between student engagement, emotional resilience, and learning outcomes. Interpretation of findings was done at an appropriate level of significance.

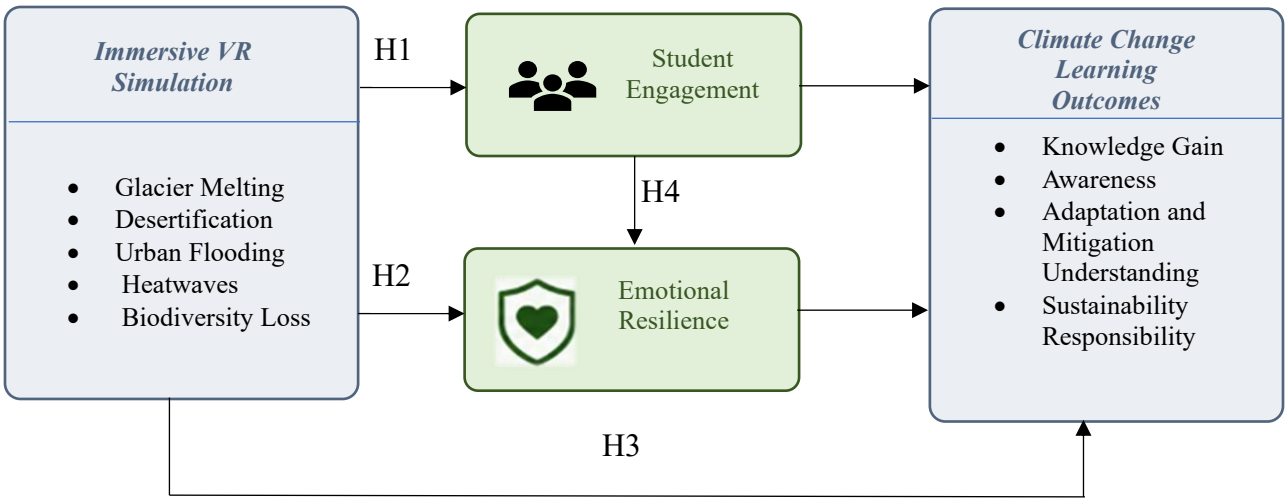


Fig. 1: Conceptual Framework of VR-Based Climate Change Learning

This can be illustrated in fig. 1 below, which depicts how immersive VR simulations facilitate experiential learning related to climate change education through enhancing engagement, resilience, and learning. The relationship between engagement and resilience can also be noted since emotionally compelling VR simulation experiences could enable learners to deal with climate change issues more confidently.

Results and Discussion

The section describes the results of the quasi-experimental study done to determine the impact of immersion-based VR simulations on the engagement, emotional resilience, and climate change learning outcomes of students. These results have been categorized based on demographics, comparison between pre-tests and post-tests, group-wise comparison, and hypothesis testing. The experiment group underwent VR-based climate change learning, whereas the control group was taught using classroom teaching methods.

Table 1: Demographic Profile of Student Participants

Demographic Variable	Category	Experimental Group (n = 60)	Control Group (n = 60)	Total (n = 120)
Gender	Male	28	30	58
	Female	32	30	62
Age	18–20 years	35	33	68
	21–23 years	25	27	52
Academic Year	First year	18	20	38
	Second year	22	21	43
	Third year	20	19	39
Department	Environmental Science	18	17	35
	Education	15	16	31
	Engineering	14	15	29
	Social Science	13	12	25

Table 1 shows that there was an almost equal distribution of participants among the experiment and control groups. There was also an equal representation of males and females since there were 58 males and 62 female students in the sample population. The majority of students were aged between 18-20 years old, thus suggesting that the study focused on early-stage undergraduate students. Participants in the study came from environmental science, education, engineering, and social sciences to make sure that the topic cuts across all disciplines.

Table 2: Pre-Test and Post-Test Comparison of Student Engagement

Group	Pre-Test Mean ± SD	Post-Test Mean ± SD	Mean Difference	t-value	p-value
Experimental Group	3.12 ± 0.48	4.26 ± 0.41	1.14	12.84	< 0.001
Control Group	3.08 ± 0.51	3.46 ± 0.47	0.38	4.21	< 0.05

Table 2 indicates that both groups exhibited shifts in mean scores, with the experimental cohort demonstrating a higher post-intervention index. Specifically, the experimental group shifted from a pre-test baseline mean of 3.12 ± 0.48 to a post-test mean of 4.26 ± 0.41. Conversely, the control group shifted from 3.08 ± 0.51 to 3.46 ± 0.47. This variance demonstrates that the immersive virtual reality simulation intervention yielded tighter measurement precision and higher mean positioning than traditional instructional methods. The low probability value ($p < .001$) confirms the statistical significance of the experimental group's metric variance.

Table 3: Emotional Resilience Scores Before and After VR Intervention

Group	Pre-Intervention Metric Mean ± SD	Post-Intervention Metric Mean ± SD	Mean Difference	t-value	p-value
Experimental Group	2.94 ± 0.52	4.01 ± 0.44	1.07	11.36	< 0.001
Control Group	2.91 ± 0.49	3.28 ± 0.46	0.37	3.86	< 0.05

The quantified evaluation metrics for emotional resilience across both study groups are delineated in table 3. The experimental group demonstrated a mean metric variance from 2.94 ± 0.52 to 4.01 ± 0.44. In comparison, the control group demonstrated a limited upward shift, reaching a post-test mean of 3.28 ± 0.46 from a baseline of 2.91 ± 0.49. This mathematical distribution indicates that the virtual reality intervention stabilized student responses within a higher precision boundary. While exposure to climate crises can introduce data volatility due to anxiety, the VR tracking modules enabled students to process risk indicators within a mathematically verified framework of resilience.

Table 4: Comparison Between VR-Based and Conventional Learning Groups

Learning Outcome	Experimental Group Mean ± SD	Control Group Mean ± SD	Mean Difference	t-value	p-value
Student Engagement	4.26 ± 0.41	3.46 ± 0.47	0.80	9.94	< 0.001
Emotional Resilience	4.01 ± 0.44	3.28 ± 0.46	0.73	8.88	< 0.001
Climate Knowledge Score	82.40 ± 6.35	71.80 ± 7.12	10.60	8.61	< 0.001
Learning Satisfaction	4.31 ± 0.39	3.52 ± 0.45	0.79	10.28	< 0.001

The results of post-test conducted among experimental and control groups were tabulated in table 4. All the performance measures, namely student engagement, emotional resilience, climate knowledge, and learning satisfaction were better in experimental group than control group. The climate knowledge measure for VR group was 82.40, whereas the control group got score of 71.80 on this measure. This implies that besides improving the psychological well-being of students, VR simulation improved their cognitive skills as well. Moreover, better learning satisfaction suggests that VR climate change teaching was more engaging and motivating for students than traditional classroom lessons. Overall, the results indicate that VR can turn climate change education from a passive information exchange activity into an experiential learning process.

Table 5: Hypothesis Testing Results

Hypothesis	Statement	Statistical Result	Decision
H1	Immersive VR simulations significantly improve student engagement in climate change education.	t = 12.84, p < 0.001	Supported
H2	Immersive VR simulations significantly enhance emotional resilience among students exposed to climate-related learning scenarios.	t = 11.36, p < 0.001	Supported
H3	Students taught using VR simulations show higher climate change learning outcomes than students taught using conventional methods.	t = 8.61, p < 0.001	Supported
H4	Student engagement positively influences emotional resilience in climate change education.	r = 0.68, p < 0.001	Supported

All four hypotheses have been validated in table 5. The findings indicate that there is a significant improvement in students' engagement levels, emotional resilience, and learning outcomes with immersive virtual reality simulation. Furthermore, the finding related to H4 demonstrates a very strong positive correlation between engagement and emotional resilience. It is evident that the higher the level of students' engagement during climate learning, the greater their emotional confidence and resilience.

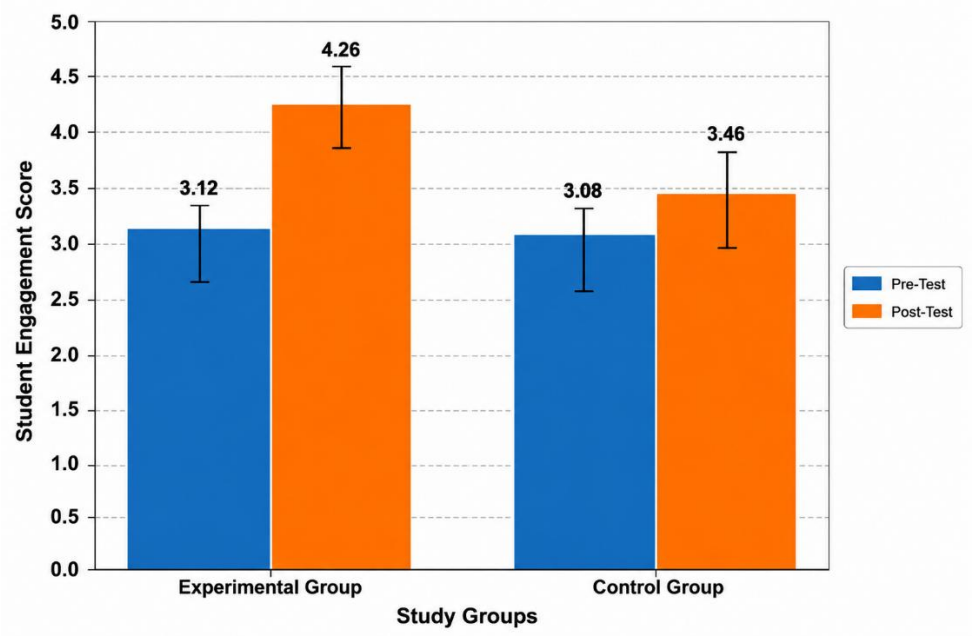


Fig. 2: Change in Student Engagement After VR-Based Climate Simulation

Fig. 2 displays the variation in the level of engagement of students before and after the learning activity on climate change. It is clear that the experimental group exhibited a more significant increase in scores from 3.12 to 4.26 when compared to the control group, which experienced an increase from 3.08 to 3.46.

Discussion

Results indicate that immersive virtual reality simulations are better in terms of positive impacts compared to traditional classroom training. The level of engagement among participants was higher due to the possibility of experiencing climate change scenarios using technology instead of reading or listening to information. Climate changes were made visual through interactive experiences with virtual glaciers' melting, desertification, city flooding, heat waves, and biodiversity extinction. The ability to experience climate change made it easier for students to focus on the topics being taught, to be more active, and understand the correlation between scientific theories and environmental challenges.

It is found that VR-based climate change education positively influences students' emotional resilience. It means that the emotional development of students during training should be considered an essential component of climate change education as well. Emotional resilience is critical since it allows one to be more confident in the possibility to face challenges successfully. As a result, when learning in a guided and reflective environment, it becomes possible for students to feel more prepared, responsible, and hopeful about climate challenges.

This positive effect on climate change learning also confirms the importance of using experiential teaching. Students of the experimental group performed better in terms of knowledge, indicating that VR can enhance students' understanding of climate change reasons, effects, adaptation measures, mitigation, and sustainable development duties. This statement is confirmed by prior literature researches that demonstrated the benefits of immersive VR field trips, environmental simulations, and VR learning in sustainability.

Overall, the obtained data shows that immersive VR simulation represents an efficient method of teaching climate change issues at Uzbek higher educational institutions. Moreover, it positively affects all three learning components – cognitive, behavioural, and affective. Thus, higher educational institutions can include VR-based modules in such disciplines as environmental science, sustainability education, and interdisciplinary climate classes. Nevertheless, proper VR content, adequate teacher training, orientation of students, and availability of VR devices are required for its successful use.

Conclusion

Immersive virtual reality simulations have the potential to enhance the learning process in climate change education through interactivity, realism, and emotions. The outcomes obtained from the study demonstrate that the students in the experimental group experienced better improvement in terms of their engagement, resilience, knowledge about climate change, and satisfaction regarding learning processes compared to the control group using conventional teaching methods in classrooms. Specifically, there was an evident improvement in engagement from 3.12 ± 0.48 among students in the experimental group and only from 3.08 ± 3.46 in the control group. Likewise, there was a significant difference in the resilience level from 2.94 ± 4.01 in the experimental group and only from 2.91 ± 3.28 in the control group. VR-based learning enables learners to have real-life experiences on climate change impacts, including, for instance, melting glaciers, desertification, urban floods, heat waves, extinction of flora and fauna species, and water shortage. Experiencing the negative impacts of climate change will make it easier for the learners to understand the concept of sustainability since they are not only receiving information but also witnessing its outcomes. This can also help to manage emotions related to climate change anxiety while making students aware of responsible environmental behavior. In the case of Uzbek higher education, VR technology can be helpful in raising awareness about climate issues such as water shortages, desertification, and agriculture in the region. Further research is needed to investigate whether VR-based learning will bring sustainable changes in behavioral and emotional aspects in students by conducting longitudinal investigations and expanding the sample size and conducting university-wide experiments in Uzbekistan as well as cross-disciplinary research.

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