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Leveraging Extended Reality for Quality Education and Classroom Atmosphere in Rural Regions of China

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Abstract

Despite access to quality education being essential for all, children and youth living in remote rural areas still struggle to gain the same opportunities as their urban counterparts. They face barriers that hinder their access to quality learning and classroom atmosphere. This study aimed to investigate the potential of leveraging extended reality to enhance quality education and classroom atmosphere in rural regions. A small-scale investigation was conducted to examine the existing urban-rural schools' educational quality (Stage 1), then mixed methods were employed to investigate a total of 70 rural students (aged 10–16) in rural China, to examine differences between extended reality-assisted education and traditional classroom education (Stage 2). The results showed that students believed their traditional class was useful, but they favoured extended reality-based education. It was concluded that extended reality-based education can be a creative approach to improve classroom atmosphere and increase educational quality in underdeveloped rural areas.

Keywords: *quality education, extended reality, classroom atmosphere, rural students, educational inequality*

Introduction

Quality education plays a pivotal role in advancing the United Nations' Sustainable Development Goals (United Nations Department of Economic and Social Affairs, 2015). It significantly contributes to individual and collective development by equipping individuals with essential competencies to explore and grow globally (Organisation for Economic Co-operation and Development [OECD], 2018; Willoughby, 2016). Even though access to quality education is essential, many countries, especially low-income countries (Asaju & Adagba, 2014; Diwakar, 2015), still struggle to offer quality education to their youth (Lewin, 2009; United Nations Educational, Scientific and Cultural Organization [UNESCO], 2022). Furthermore, access to quality education can differ within countries. Unlike low-income countries with low educational quality, in a middle-income country like China, access to quality education presents a complex situation where high-quality education and poor-quality education have long coexisted (Rao & Ye, 2016; Rozelle & Hell, 2020). This educational gap is especially noticeable in the divide between China's advanced urban regions and remote rural regions. For example, in the 2018 OECD Programme for International Student Assessment test, China's four most advanced provinces—Beijing, Shanghai, Jiangsu, and Zhejiang—ranked first (Peña-López, 2019). Their scores exceeded their counterparts from the other 78 participating countries and regions by a large margin (Peña-López, 2019). However, students from lower income provinces with under-developed rural areas have performed amongst the lowest in China's student population. In China's north-west rural areas, the average two-year dropout rate in grades 7 and 8 ranges from 7.2% to 27.1% (Wang et al., 2015).

Literature Review

Research highlights several elements that shape quality education in the classroom: proficient teachers (UNESCO, 2016), well-designed learning materials, and pertinent instructional methods (Mok & Chan, 2001). Another critical factor that affects the quality of learning is the classroom atmosphere, which has been defined as everything that takes place in an educational department, such as classroom setting, faculty, school, or university (Ofoghi et al., 2016). Research indicates that students who value the classroom atmosphere more positively achieve better academic performance and form a stronger sense of belonging at school than those who evaluate it more negatively (Cerón et al., 2016; Hamid et al., 2013).

When used correctly, extended reality (XR) as part of the learning experience can lead to a positive classroom atmosphere (Utami et al., 2021). Previous studies have found that XR can assist teachers and students in building trust, understanding, and constructive interactions, improving multi-dimensional classroom climates (Santos Garduño et al., 2021). By learning through virtual reality and augmented reality, students can access various resources, be involved in the setting, and learn through touch, space and motion by physically interacting with the virtual system (Markowitz et al., 2018). This system can enhance experiences in the classroom by providing safety, interactivity, simulation, and multisensory engagement, which further create a learning-friendly atmosphere for classroom activities (Wang et al., 2021). Within a positive classroom atmosphere, students' self-regulation and motivation can be triggered by well-designed XR classes (Wang et al., 2021).

Classroom teaching and learning are vital components of quality education, as students acquire the knowledge and skills that they need to achieve future success (Kasem & Pathak, 2014; Shirani Bidabadi et al., 2016). Amid the digital transformation of classrooms, knowledge about immersive media, such as XR technologies, is critical, as this may play a key role in ensuring quality education and classroom atmosphere for future students (Pimentel et al., 2022). XR is a catch-all term that encompasses augmented reality, mixed reality, and virtual reality technologies, which can be placed on a continuum, moving from complete reality to complete virtuality (Milgram & Kishino, 1994). In essence, these technologies allow us to "*go beyond our physical reality*" (Pimentel et al., 2022, p. 2), with devices such as tablets, desktops and virtual reality headsets (Angelov et al., 2020). Because the cost of XR is decreasing, using technology-supported interventions is becoming a feasible option for rural education. One advantage of XR is that it offers a cost-effective way for rural students to access diverse educational experiences in their classrooms. However, there is limited research on using XR in non-WEIRD (Western, Educated, Industrialised, Rich, and Democratic) samples (Wang, Young, Plechatá, et al., 2023).

XR may help teachers provide opportunities for active participation and collaboration and personalised and adaptive learning experiences (Xie et al., 2019). It has the potential to meet students' needs, such as helping under-represented groups gain access to quality education that their peers from well-developed regions already possess (Wang, Young, Iqbal, et al., 2023). However, few studies have explored XR's potential for improving quality education and classroom atmosphere. Furthermore, to our knowledge, no studies have been conducted on this topic in socioeconomically disadvantaged populations, such as rural China. Research is needed to investigate the feasibility of technology-supported educational interventions to improve educational quality and classroom atmosphere for these populations.

Efforts to address educational inequality have often involved the introduction of asynchronous learning platforms as supplements to education in disadvantaged areas (Gottschalk & Weise, 2023). In contrast, this article reports the results of a study that introduced XR-enhanced education directly into classrooms in remote rural areas in China, and investigated its potential to improve the quality of education offered there. To achieve this goal, four hypotheses were developed:

H1: There is a significant difference in students' perceived quality of education between urban and rural China, potentially influenced by access to educational resources and teacher support.
H2: XR-assisted education can improve rural students' perceived education quality in learning, enthusiasm, organisation, group interaction, individual rapport, breadth, examinations, and assignments.
H3: XR-enhanced education improves classroom atmosphere in terms of student cohesiveness, teacher support, involvement, investigation, task orientation, cooperation, and equity.
H4: Rural students are more likely to give positive feedback on their XR education experiences due to the novelty of the technology and its perceived usefulness in enhancing understanding.

The Current Study

This study set out to critically assess the feasibility and effectiveness of using XR technology to enhance students' educational well-being, specifically in underdeveloped regions of China. To achieve this goal, we selected China's (rural) education and students as our research object and sample population, given that rural areas in China have a high number of children (about 100 million), and the educational chasm between urban and rural China has been a long-standing topic of discussion among organisations (e.g., National Working Committee on Children and Women, National Bureau of Statistics, & United Nations Children's Fund, 2018; OECD, 2018) as well as experts (e.g., Rozelle & Hell, 2020). Thus, this study contributes to a broader conversation about the role of emerging technologies (i.e., XR) in advancing educational equity and access, by exploring the use of XR to augment learning experiences in rural China.

Before conducting this formal experiment, we addressed fundamental thinking as a prior question: Does China's urban-rural education inequality still exist today? This was informed by an increasing number of studies that have claimed that the educational gap between urban and rural China has been reduced (Cai & Wu, 2019; Qi & Melhuish, 2017). To answer this question, a pilot investigation was conducted to examine whether the chronic educational inequality between China's developed urban areas and underdeveloped rural areas still exists. Hypothetically, the pilot study confirmed this.

Next, a mixed methods research design was employed to examine the proposed four hypotheses. First, a quantitative study investigated the potential education quality gap between rural and urban China (H1). Second, the feasibility of XR education for rural schools' class quality (H2) and classroom atmosphere (H3) were examined. Thirdly, to test H4, a qualitative investigation was conducted with the same cohort to understand (a) students' perspectives on their XR learning experience, and (b) students' outlook on how XR education changed and impacted their learning in a specific rural context. This research design was approved by the university research ethics committee prior to the initiation of the data collection.

Stage 1 Study: A Small-Scale Pilot Investigation

To examine whether an educational gap was present between urban and rural China, potentially influenced by access to educational resources and teacher support (H1), 120 Chinese students aged 10–18 years were recruited: 60 from four provinces in South and West China, known for their massive rural areas, and another 60 from East China's three metropolitan municipalities which are known as China's most developed regions. Eight students dropped out from the questionnaire filling phase, which led to a final sample of 57 rural students (28 female; a mean age of 14.26) and 55 urban students (22 female; a mean age of 14.76) completing the pilot study.

All students and their guardians were provided with participation information and consent forms to join the experiment, which set out to identify rural and urban students' perceptions of educational quality in mainstream subjects. Therefore, participants were invited to fill out the *Student Evaluation of Educational Quality* questionnaire (SEEQ) to report their evaluation (Marsh, 1986) of learning Chinese Literature, Mathematics and English.

The SEEQ contains 29 items covering eight dimensions (see Table 1), and the students rated items as Very Poor, Poor, Average, Good or Very Good. Table 1 shows means and standard deviations for the urban and rural students' responses to the questionnaire, as well as statistical results when comparing the two groups.

Table 1: ***Urban-Rural Students' Differences on the SEEQ Questionnaire, with Statistical Results***

	Urban Students		Rural Students		Statistical Results			
Dimensions of the SEEQ	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**	**Degrees of Freedom[a]**	**t-test[b]**	**Significance 2-sided[c]**	**Cohen's D[d]**
Learning	14.67	3.23	11.67	1.86	110	6.06	< .001	1.15
Enthusiasm	15.85	3.60	11.25	1.80	110	8.62	< .001	1.63
Organisation	16.09	3.18	10.78	1.68	110	11.14	< .001	2.11
Group interaction	15.95	3.69	9.86	1.88	110	11.06	< .001	2.09
Individual rapport	14.82	2.74	10.74	1.68	110	9.66	< .001	1.83
Breadth	15.62	3.22	12.48	1.70	110	6.50	< .001	1.23
Examinations	11.84	2.75	8.07	1.79	110	8.61	< .001	1.63
Assignments	8.03	1.73	5.30	1.38	110	9.28	< .001	1.76
SEEQ total	112.87	20.77	80.12	6.95	110	11.27	< .001	15.37

[a] The number of independent values in a dataset that can vary without violating any constraints. [b] Compares the means of the two groups to see if they differ significantly. [c] Indicates whether the difference between the two means is statistically significant in either direction. [d] Compares the difference between two means as standard deviations.

Although the sample size is relatively small, the SEEQ results (Cronbach's alpha, $\alpha = 0.97$) from the independent samples t-test showed the two groups of students' (rural and urban) perceived educational quality in the three mainstream subjects (Chinese Literature, Mathematics, English) as significantly different ($p < 0.001$). Following our rationale, this small-scale investigation result required a further study on the use of XR education in rural schools and its effectiveness in supporting quality education.

Stage 2 Study: Mixed Methods

In Stage 2 of this study, a total of 70 rural students (10–16 years old) were recruited from two different schools in Western China to participate in a mixed methods study. This cohort was different from the cohort in the Stage 1 study. All participants were randomly divided into two groups: the experimental group and the control group. The experimental group was assigned as the XR group (n = 34, 28 female, mean age = 13.35), and the control group was assigned as the traditional class group (n = 36, 22 female, mean age = 13.58), as shown in Table 2.

Table 2: ***Demographic Characteristics of Stage 2 Participants***

Participant Groups	Number of Participants	Number of Females (%)	Mean Age (SD)
XR (experimental)	34	28 (49.12)	13.35 (1.55)
Traditional class (control)	36	22 (40.0)	13.58 (1.52)
Total	70	50 (44.6)	13.47 (1.53)

Three questionnaires were used to collect quantitative data:

- *The Student Evaluation of Educational Quality Questionnaire* (SEEQ), described earlier.
- *The What Is Happening in This Class Questionnaire (WIHIC)* (MacLeod & Fraser, 2010), a widely applicable questionnaire for measuring students' perceptions of classroom atmosphere, with 56 items and seven sub-scales.
- *User Experience Questionnaire* (UEQ) (Schrepp et al., 2014), an internationally recognised post-task questionnaire measuring the user experience of interactive activities and products.

The experimental and control groups were asked to complete a pre-test and post-test on the SEEQ (Marsh, 1982) and *WIHIC* (MacLeod & Fraser, 2010). The XR (experimental) group was invited to also answer the UEQ, to investigate the human-computer interactivity between students. Two-way repeated measures ANOVAs and post hoc paired-sample t-tests were used to examine differences over time, while independent samples t-tests were used to investigate differences between groups.

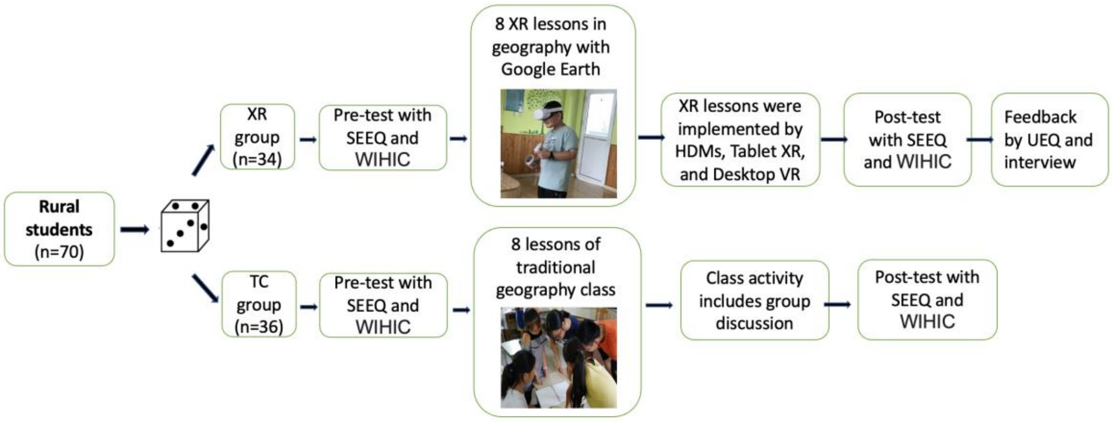
The XR group was also invited to participate in an individual semi-structured, qualitative interview, and a total of 34 students participated. The interviews were conducted in an empty classroom and ranged from 6 to 18 minutes in duration. The interviewees were informed that it was a two-way communication process, and their responses and opinions were highly valued. They were encouraged to answer the questions, but they were also told that it was not compulsory to respond to all questions and they could withdraw at any time. Figure 1 shows a visualisation of this experimental procedure. A thematic analysis was performed on the qualitative data, inspired by Braun and Clarke's (2006) guidelines.

The interviews gathered qualitative, open-ended data from all the students in the XR group, to obtain their feedback on XR education. A set of 10 interview questions was designed to explore their in-depth thoughts, feelings, and beliefs regarding XR-assisted teaching and learning in their rural context. The interview questions were:

1. What do you think about the XR lessons you took?
2. What do you think of the classroom atmosphere during the XR lessons?
3. How would you rate your overall XR experience: "liked it," "neutral," or "disliked it"?
4. Which lesson did you enjoy the most?
5. Have you learned something from the XR journey?
6. Do you enjoy interacting with the instructor when having XR lessons?
7. Do you think it helped your learning?

8. Would you be interested in more XR activities in the future?
9. Were there any limitations of your XR experiences?
10. Is there anything else you want to say that I didn't ask about?

Figure 1. Stage 2 *Experimental Procedure*



Abbreviations: TC: traditional classroom; HDMs: head-mounted displays; VR: virtual reality.

Implementation of the Stage 2 Experiments

Both the XR group and traditional class group received eight Geography lessons (Table 3). The specific learning content for each topic was developed by local rural teachers who followed the guidance of the national syllabus, as per the geography textbook for grades 6 and 7, thus ensuring that the students were taught the appropriate content for their age group. The class included teaching and group discussions. The design of the classes matched best practice guidelines, suggesting that immersive lessons are most effective when they are based on their affordances in combination with other instructional methods. In this case, the XR part of the lessons was presented at the beginning of each class, to spark situational interest before using other instructional approaches.

Table 3. *Course Plans for XR and Traditional Class Groups*

XR Group (Experimental Group)			Traditional Class Group (Control Group)		
Themes	**Main Platforms**	**Duration**	**Topics**	**Main Platforms**	**Duration**
Planetary exploration on the Moon	Google Earth by Meta Quest 2 and tablet	2 lessons x 35–40 mins	Introduction to Astronomy	Smart whiteboard and textbook	2 lessons x 35–40 mins
Planetary exploration on Mars	Google Earth by Meta Quest 2 and tablet	2 lessons x 35–40 mins	Moon and Mars trip	Smart whiteboard and textbook	2 lessons x 35–40 mins
A glimpse of foreign communities	Street View by XR with tablet and laptop	2 lessons x 35–40 mins	World geography	Smart whiteboard and textbook	2 lessons x 35–40 mins
Visiting famous attractions	Street view by XR with tablet and laptop	2 lessons x 35–40 mins	Life in Western communities	Smart whiteboard and textbook	2 lessons x 35–40 mins

XR Group Course Implementation

For the XR (experimental) group, the contents of the lessons were placed within four themes (see Table 3). Each lesson lasted 35–40 minutes, twice a week for four weeks. The XR group used Google Earth virtual reality and Street View. Google Earth virtual reality provides three-dimensional representations of the Earth using satellite imagery (Google Earth, 2022), and these can be accessed through desktop computers, smartphones and tablets. For instance, Street View allows students to see streets, cities and landscapes from various angles (Gartenberg, 2019).

Each XR lesson consisted of three segments implemented in virtual reality, as shown in Figure 2. The students:

1. watched a 5–10 minute virtual reality 360-degree immersive video via Meta Quest 2 (e.g., Spacewalk Experience);
2. went to the Moon and Mars through Google Earth by tablet or visited famous attractions (e.g., Angkor Wat, Eiffel Tower) using Street View by tablet for 20–25 minutes;
3. engaged in a question-and-answer time (5–10 minutes), and were encouraged to play the desktop XR and discuss the learned content and the lesson's teaching goals with their peers and instructors.

Figure 2: ***The Segments of XR Education***

Abbreviation: VR: virtual reality

Traditional Class Group Course Implementation

The traditional class course plan used a traditional teaching approach with learning content similar to the XR group (see Table 3). The lessons aimed to help children develop astronomical and geographical investigating. Lesson plans and classroom activities were designed as cross-subject learning in astronomy, culture and geography. Each topic was covered in two lessons of 35–40 minutes, with teaching and group discussions. In each lesson, the teacher gave a lecture for 25–30 minutes, covering the main topic of the lesson, then the students had a group discussion for 10–15 minutes, allowing them to share their thoughts and ideas on the topic. The primary media was the smart whiteboard, as shown in Figure 3.

Figure 3: ***The Traditional Classroom Using Smart Whiteboards***

Results of the Stage 2 Study

Quantitative Results

The Stage 2 study addressed three of the four hypotheses: H2, H3 and H4. H2 was examined by comparing the XR and traditional class groups' answers to the SEEQ (see Table 4). There was a significant main effect of time, $F = 256.94$, $p < .001$, $\eta 2 = .791$. Two post hoc dependent measures t-tests showed that both the scores of the XR group ($t = -14.172$, $p < .001$, $d = -2.431$) and the traditional class group ($t = -7.406$, $p < .001$, $d = -1.234$) increased over time. In summary, the results indicated that both the XR and the traditional class groups significantly increased their perception of educational quality from the pre- to the post-test and that the XR group increased significantly more over time than the traditional class group did.

Table 4: ***Two-Way Repeated Measures ANOVA Results for SEEQ and WIHIC, including WIHIC Sub-Scales***

	Time			Interaction		
Questionnaire or Sub-Scale	**F**	**P**	**η2**	**F**	**P**	**η2**
SEEQ total	256.945	< .001	0.791	142.940	< .001*	0.678
Cohesiveness	11.903	< .001*	0.149	2.843	.096	0.040
Teacher support	23.133	< .001*	0.254	11.803	.001*	0.148
Involvement	2.377	.128	0.034	9.186	.003	0.119
Investigation	12.044	< .001*	0.150	7.379	.008	0.098
Task orientation	11.122	.001*	0.141	5.793	.019	0.078
Cooperation	3.237	.076	0.045	0.249	.619	0.004
Equity	7.064	.010	0.094	0.597	.442	0.009
WIHIC total	23.214	< .001	0.254	8.966	.004*	0.116

* Significant at $\alpha = .05$, for the WIHIC sub-scales. A Bonferroni correction of $\alpha = .007$ was used.

To examine H3, we compared the scores of the XR and traditional class groups on the WIHIC questionnaire (see the final row of Table 4). There was a significant main effect of time, $F = 23.214$, $p < .001$, $\eta 2 = 0.254$. Two post hoc dependent measures t-test showed that the XR group increased over time, $t = -5.584$, $p < .001$, $d = -0.958$, while the traditional class group did not, $t = -1.279$, $p = .105$, $d = -0.213$. There was a significant interaction effect between group and time, $F = 8.966$, $p = .004$, $\eta 2 = 0.116$.

In further analysing the sub-scales to understand better the XR and traditional class interventions, the results indicated that the XR group significantly increased their general perception of the classroom atmosphere. However, the increase for the traditional class group was not significant. Furthermore, the sub-scales of teacher support and involvement were specifically where the XR group increased significantly more than the traditional class group.

The User Experience Questionnaire (UEQ) and the semi-structured interviews were used to answer H4. Students rated attractiveness as 1.961 (SD = 1.05), perspicuity as 1.588 (SD = 1.13), efficiency as 1.5 (SD = 0.9), dependability as 1.63 (SD = 1.07), stimulation as 1.74 (SD = 1.16), and novelty as 1.43 (SD = 1.15). This puts all the scales above the criteria of 0.8, which is defined as a positive evaluation on all sub-scales. This suggests that, overall, students found the employed XR technologies to be understandable and engaging.

Qualitative Results from the Semi-Structured Interviews

The analyses of the interview data identified three overarching themes, with sub-themes as shown in Table 5.

Table 5: ***Themes and Sub-themes Identified in the Interview Data***

Themes	Sub-themes
Course content	1. Impression of XR-assisted education 2. XR technology in the eyes of rural students
Learning	3. Learning accessibility and comprehensibility 4. Classroom atmosphere and learning environment 5. Learning approach and practice
Conflicts between learning interest and goal	-

In the course content theme, students explored different parts of the world via XR to gain more knowledge of astronomy, geography and culture in a novel way. This gave them more chances to glimpse Western street views and communities in Google Earth XR. A prominent topic of discussion was the students' impression of the technology-enhanced class (sub-theme 1). For many of the students, this way of learning was unfamiliar, but novel. It opened up a whole new perspective on learning and how to interact in the classroom: "*It's all something we learned in geography class, but it's not the same feeling*" (Student 3). Many students praised the ability to delve into the material and explore it as a key reason for their positive experience with the XR class. They found it convenient to visit many distinct places in XR while still being in the classroom, and found the immersive experience both surprising and motivating.

However, some students were worried that this type of learning would not directly benefit their exams. While there were some disagreements among students in relation to the course content in learning, the majority reported that it was a more relaxed and engaging way to learn, compared with the traditional pedagogy.

Students' overall experiences in XR learning (sub-theme 2) were positive. For example:

> *Through this course, we can go where none of us can go. Not only foreign countries but also those planets, which are different from what we see in the textbooks. Textbooks are just photos, some in black and white, but what you see in XR is similar to real scenes and objects. (Student 1)*

This made some of the students wonder how this technology might help with accessing difficult-to-grasp knowledge. For instance, one student speculated that XR technology could make STEM subjects more intuitive by visualising complex and abstract models. At the same time, in some cases students who initially felt out of their comfort zones using the technology expressed that they grew more familiar with XR classes during the course. As a result, "*this kind of learning gradually became clear, and I learned more and more things*" (Student 12). As the use of XR technology in the classroom becomes increasingly common, it is critical to consider how to support students in navigating these new learning environments.

In the learning theme, some students found it challenging to interact with these new technologies; however, students' general sentiment was that this technology-enhanced course made learning easier. This could be attributed to the fact that XR education made the learning goals more comprehensible, by providing clear and illustrative concepts and examples (sub-theme 3). Students believed that they were imparted more flexible and multi-faceted knowledge, allowing them to have a deeper understanding of the context and background of what they were learning. For example, Student 7 mentioned that the XR experience enabled them to form a more vivid memory of the content, making it easier to recall their experience, because it was now represented as a visualised environment rather than just text in a book: "*I can feel I was inside of the venue, and I can remember many details of what I have seen and learned.*"

However, some students also expressed that the learning goals of the technology-enhanced learning environments were not clearly aligned with their ordinary classes. This made them worry whether this kind of studying would be suited to preparing them for their exams.

Students valued XR education as a better way to enhance the atmosphere in the classroom since it fostered a more dynamic and collaborative classroom atmosphere (sub-theme 4). They experienced greater engagement with the learning environment, including the XR classroom environment that was different from the traditional teacher-centred method with rules and disciplines. The XR-enhanced classroom atmosphere was more inquiry-based, combined with games and adventures. This was different from the classroom atmosphere students were used to, where the focus was on studying and exams, often accompanied by limited interactions and teaching methods that generated tension in the classroom atmosphere.

However, some students felt the XR classroom was less disciplined than their usual classroom, since some of the students became too excited or were shouting during the class, which disrupted the peaceful atmosphere for them. This change of atmosphere might refer to different teaching styles between the XR class and the traditional class.

XR-enhanced teaching and learning were creative and led students to understand that they were given various learning experiences (sub-theme 5). Given that XR-enhanced education reduced the didactic teaching load in the classroom, students relied less on the teacher and enjoyed the classroom atmosphere more:

> *The atmosphere of this XR class was quite special because we have time to study with classmates, by ourselves, and to study and discuss with the teacher. These three forms all made the class very short, and you felt like time passed quickly. (Student 20)*

At the same time, some of the students preferred the gamified elements, which made the classes "*not boring at all*" (Student 7). However, there was no homework. Student 7 indicated that "*if we* *keep studying in without any homework and continue to do this in the future, we may not get good grades.*" Students valued that XR classes were closer to extracurricular activities: "*the content in the XR class cannot improve our academic performance too much because the design is based on interests*" (Student 31), while the content in the traditional class was mainly designed for competitions.

In relation to the theme regarding conflict between learning interest and goal, we found that students developed a mental divide between stress-free learning and structured learning; that is, they had conflicts between their traditional learning experiences and XR learning experiences. They appreciated the use of different teaching methods and multiple technologies, which enabled them to learn in different ways and rely less on traditional teaching styles. Student 20 noted that the XR classroom environment was unique, with diverse combinations for experiencing different XR formats with individual study, group study and teacher-led discussion. This varied approach made the class feel more dynamic and engaged than traditional classrooms.

However, some students felt that the technology-enhanced learning was too different from traditional classes. It had a perceived focus on games and fun rather than exam preparation, and it lacked homework and related practices. Students expressed concern that, without the structure of traditional classes, they might not perform well on future exams. They actively compared structured learning (rote learning) to learning for fun (exploration), and these comparisons might distract them from focusing on the value of the learning itself.

These perceptions reflected students' understandings of what real learning is in remote rural contexts. There appears to be a distinct understanding that relates to the international mainstream education advocacy for inclusive and quality education and lifelong learning for all (OECD, 2021; United Nations Department of Economic and Social Affairs, 2015). Education can provide people with the knowledge and skills they need to stay healthy, get jobs and foster tolerance (UNESCO, 2019).

Discussion

Implications of the Quantitative Studies

This study used mixed methods to investigate whether XR education could improve educational quality for students who live in remote rural areas. The results from our pilot study suggested that educational inequality might still exist between China's rural and urban areas, even though the government has given substantial financial support to all rural schools. Our study illustrated that leveraging XR technology could be an effective way to give teachers easily accessible classroom materials that may enhance the quality of teaching and learning (Utami et al., 2021).

Results from the SEEQ indicated that students perceived that both conditions (i.e., XR and traditional class) significantly enhanced educational quality. Overall, the XR group's scores increased more over time in regard to the quality of education and the dimensions of breadth and assignments than the traditional class group's scores. This could indicate that XR enabled rural students to access a wider range of resources that were not available to them in their usual classrooms (Pimentel et al., 2022), because of the disadvantaged conditions connected to rural teaching and learning, such as taking place in a remote location, using outdated educational facilities, and having a higher proportion of parents with low socioeconomic status and, connected to this, lower incomes.

The XR technology might have increased the breadth of the course by expanding the number of things it was possible for the students to experience, such as visiting Mars and the Moon, different countries, and famous sites, all without needing to leave their classrooms. Compared to following the script within traditional classrooms, XR classes integrated design features involving creativity and interactivity to kindle students' motivation in active learning.

Results from the WIHIC showed that students perceived that the general classroom atmosphere was significantly enhanced by both conditions (XR and traditional class). At the same time, evident enhancement was also perceived in teacher support for students, an essential component of promoting student learning and well-being, as well as involvement, referring to the engagement of students, teachers and other stakeholders in the learning process. The follow-up t-test findings showed that the XR group's impression of the general classroom atmosphere increased more over time than the traditional class cohort, specifically in teacher support and involvement. The results regarding teacher support could be attributed to a lower student-teacher ratio. However, it could also be connected to the technology-enhanced classroom having a more active classroom atmosphere, which might lead to increased learning and an increased feeling of engagement due to increased interactivity between all stakeholders, and therefore an increased feeling of Involvement (Tegoan et al., 2021).

Within the XR classroom, due to the small teacher-student ratio (1:2 or 1:3), the instructor was able to recognise and respond to each student's needs and provide timely and tailored support for personalised learning. Given that the teacher-student classroom ratio in participating rural schools varies from 1:30 to 1:65, it is often challenging for teachers to provide individualised attention and support to students, and this can reduce the quality of education. Furthermore, XR supported classroom environments have been shown to provide multiple types of learning experiences, such as increased immersion, active participation and hands-on experience, as well as a sense of safety and manoeuvrability, which might all help teachers create an atmosphere of positivity with diverse educational experiences.

User Experience Reflections

The UEQ results showed that students evaluated XR education as holding a good level of perspicuity and efficiency. This might be partially explained by Google Earth's clear and intuitive user interface that makes it easy for rural students to navigate and access information. Additionally, clear, concise instructions were presented to the students before they were given access to the XR headsets. This might have helped the students more easily understand what they were expected to do and how to use the technology.

Students also reported that the virtual reality technology was attractive, stimulating, and novel to them. This is in line with prior research. Many studies have noted that immersive XR is more likely to provide students with a sense of novelty, recreational stimulation, and excitement (Wang, Hodgers, et al., 2022). However, we wonder if this can last only for a short period of time, rather than enhancing students' learning motivation and helping them maintain this momentum. In fact, the ideal situation would be that technology, including XR, is used strategically to support teaching and learning (Wang, Quirke, et al., 2022). Many rural schools even have access to some basic technological equipment already, such as whiteboards and computers. However, many teachers are not willing to adopt these new technologies and integrate them into their classes. Hence, even with the literature indicating that XR may be an effective educational technology (Wu et al., 2020), and the current study finding support for the technology having a positive effect in underdeveloped rural areas, this might not be enough for the technology to be accepted and used by school environments.

Rural Students' Perspectives on XR Education

In comparison to the traditional class group, the XR group mainly valued that they experienced extra intriguing learning and human-computer interaction through XR education. The ease of learning via XR increased the enjoyment of students' classroom time, which directly led to a livelier and more positive atmosphere in the rural classroom. The students highlighted how their learning in the technology-enhanced environment seemed to be more driven by interest, which might lead to increased learning, but also increased interest in school subjects outside of school, according to interest theories such as the four-phase model of interest development (Hidi & Renninger, 2006).

Nevertheless, a key topic of discussion among students was whether their exam results, which were always prioritised in their studies, would be affected by the innovative XR learning, because, without an excellent test result, rural students are more likely to be eliminated by future entrance examinations (Rozelle & Hell, 2020). This makes us ponder whether educational freedom and reform can still be developed and improved under an exam-oriented system, because traditional education often infiltrates competition and compliance into students' minds, and this maintains power structures and hidden inequalities (Freire, 1970).

This also seems to reflect the two distinct pedagogies of student-centred and teacher-centred learning, where traditional education seems to be closer to teacher-centred pedagogy. When the students are presented with student-centred learning, they do not recognise it as learning, because it seems more akin to extracurricular activities. This also could be connected to the fact that the subjects in the XR class were chosen by the researchers and, as such, may have been less clearly connected to the students' learning goals in their traditional classroom. However, XR has been widely used in education and has the potential to improve average learning outcomes (Tai et al., 2022). The results in the current study suggest the need for further research in a wider rural educational context.

Even after the students had reflected on both the pros (e.g., learning materials, learning approach, virtual field trips) and cons (e.g., broad learning content, noisy classroom, over-entertaining) of the technology-enhanced classroom, the majority of them (75%) still stated that they would like to explore more in XR education. Some of them also showed signs of individual interests being developed, wanting to go in the future to the places they visited in XR.

The positionalities expressed by the students could thus be mirroring that these learners actively participated in the process of the technology-enhanced education and became agents of their own exploration. In this way, technology-enhanced education can be seen as a useful toolkit to improve educational quality and for increasing students' ability to engage in their learning not only during, but also outside, the school context. This also shows how technology-enhanced education could be an important step forward for education in underdeveloped countries and regions.

Limitations

While this article provides valuable insights into using XR-supported teaching in rural settings to enhance classroom atmosphere and quality education, it also has limitations that should be considered when interpreting the findings and considering future avenues for research. While efforts were made to align educational topics as much as possible, the traditional class condition utilised materials already developed to match schools' curriculum and learning objectives. In contrast, the XR applications consisted of pre-existing materials not tailored to schools' curriculum. Additionally, there was an imbalance in student-teacher ratios between the two conditions, with significantly fewer students per teacher in the XR condition, potentially enabling more individualised student support. This misalignment suggests the potential of exploring different forms of supervision (e.g., AI-based) to support teachers in the future.

It is worth noting that traditional class teachers were sourced from the school, while XR teachers were researchers from the project. This could have contributed to the differences in pedagogical approaches, as the rural teachers may have been trained differently from the researchers. Therefore, future research should aim for greater comparability and ecological validity by utilising more closely matched educational content, equalising student-teacher ratios across conditions, and training schoolteachers rather than relying on external researchers.

Conclusion

This study explored the potential of XR technology in improving educational quality for students in remote rural areas of China. Quantitative analysis revealed significant improvements in educational quality for students experiencing XR-enhanced teaching compared to those receiving traditional classroom teaching. The same was seen for the classroom atmosphere, where students in the XR group reported higher teacher support and involvement. These findings were supported by the qualitative data, which suggested that XR-enhanced teaching can ignite students' interests beyond the classroom, potentially fostering lifelong learning. Furthermore, the students generally evaluated the XR-enhanced course positively. However, students were also critical of the novel learning approach. They wondered whether this kind of learning would prepare them for their exams rather than just introducing fun and games into the classroom. This commentary could be a valid critique of the currently available educational content for XR technologies, which is not optimised for school curricula.

On the other hand, this critique could reflect students being situated in a cultural, educational context in which teacher-centred, examination-focused education is the expected norm, making it difficult for students to evaluate student-centred, interest-driven education as actual learning. Going back to the research questions, we found that XR-enhanced education improved the quality of education and the classroom atmosphere in rural Chinese classrooms, with the students generally evaluating the introduction of technology positively, but being unsure of its value in learning.

Limitations should be addressed in future research, such as aligning the content in the XR-enhanced and traditional classrooms and the student-teacher ratios. Similarly, not all the students were familiar with the technologies employed, meaning that they might not have benefitted optimally from the XR-enhanced teaching and might have had difficulties expressing their perceptions of the distinct technologies. Generally, however, utilising XR technologies in rural classrooms can be one way to bridge educational disparities, address the United Nations' Sustainable Development Goal 4 (UN Department of Economic and Social Affairs, 2015), and improve the classroom atmosphere and quality of education for students in disadvantaged regions.

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