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The Peculiarities of an Interplay Between School Teachers and Students in a Virtual Reality when Studying Mathematics

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Abstract: The aim of the article is to describe an interplay between school teachers and students in virtual reality when studying mathematics and to reveal its peculiarities in order to maximize the virtual learning environment. This study seeks to achieve the following objectives: to explain the models of interplay between school teachers and students; to outline methodical, organizational, technical, and psychological peculiarities affecting the implementation of a productive interplay; to study the teaching methods enhancing the productivity of interplay; and to reveal the requirements to teachers' training course on the organization of productive interplay in virtual reality. The research was carried out on the basis of observation methodology involving systematical watching, recording, and analyzing the interactions between teachers and students in the learning environment. The research was organized between September and November, 2023, involved the population of 34 school teachers from five secondary schools. The findings showed that an interplay between teachers and students refers to the dynamic exchange of ideas, feedback, and support within the educational process. A productive interplay between school

teachers and students is based on positive communication, clear instructions, mutual respect, empathy, flexibility, and use of collaborative and cooperative approaches to teaching. An interplay between school teachers and students in VR when studying mathematics can be implemented through collaborative learning model, interactive model, student-centered model, flipped classroom model, and peer learning model. Besides, an interplay involves methodical, organizational, technical, and psychological peculiarities affecting its productivity. The research outlined the teaching methods oriented towards the maintenance of a productive interplay between school teachers and students in VR when studying mathematics. It was proved that the incorporation of VR tools in the mathematics classroom demands advanced teachers' training to use this technology effectively. The findings may be used at the institutions of higher education training future mathematics teachers to update their curriculum.

Keywords: communication, mathematics competence, productive interplay, teaching methods, virtual learning environment, virtual reality tools, visualization.

Introduction

Virtual reality (VR) refers to a computer-generated simulation of a three-dimensional environment that can be interacted with in an apparent real-time manner using special electronic equipment (Hamad & Jia, 2022). The technology aims to simulate the senses as realistically as possible and allows users to explore objects or phenomena virtually in the artificial world. According to Marougkas et al. (2023), VR has significant educational potential encouraging learners to be involved in real-life scenarios without leaving the classroom. The analysis of pedagogical literature showed that VR has various types of applications used in education. They include virtual trips, virtual laboratories, simulation-based exercises, language learning tools, interactive 3D models as well as instruments to train soft skills (Campos et al., 2022; Zhao et al., 2023). Such number of applications allows not only to enhance students' understanding by providing a realistic and interactive experience but also to conduct experiments or practice without real-world consequences

The adoption of VR in education is growing rapidly, supported by profound market expansion and investment. Some studies (Smutny, 2022) demonstrate that VR in education market was valued at USD 1.8 billion in 2021 and is expected to reach USD 12.6 billion by 2026, reflecting a compound annual growth rate of 47.7%. This growth is fueled by the increasing integration of VR tools in K-12, higher education, and corporate training programs. Other findings revealed that 81% of respondents believe VR have a positive impact on students' learning outcomes and enhances the efficiency of the learning environment significantly (Marougkas et al., 2023). As VR technology continues to advance and becomes more affordable, its presence in education gradually gets more common, revolutionizing teaching and learning practices.

Studying the use of VR tools in education, the special attention was paid towards their advantages. For instance, Campos et al. (2022) state that VR creates realistic simulations and environments where students can interact with educational material actively. Certain investigations showed that VR helps to accommodate various learning styles and needs resulted in organization of personalized learning environment (Zhao et al., 2023). This allows students to progress at their own pace and revisit challenging concepts as needed. According to AlGerafi et al. (2023), personalized learning makes VR an effective tool for differentiated instruction, building individual learning paths and supporting diverse learners in achieving their educational goals. Besides, it was found that VR democratizes education by making high-quality learning experiences accessible to students regardless of their geographic location or socioeconomic status. It also bridges the gaps in resources by providing virtual access to specialized equipment and facilities that are unavailable in certain schools (Elmqaddem, 2019).

The recent findings on the research topic describe the advantages which VR brings in mathematics education (Çakıroğlu et al., 2023; Serin, 2020). Firstly, it provides the activities that simplify complex concepts and enhances students' engagement as well. VR helps to transform abstract symbols and equations into visual experiences and students are able to see and manipulate 3D geometric shapes, graphs, and mathematical models. Other works prove that VR in mathematics education promotes active learning and increases motivation (Rodolico & Hirsu, 2023). Instead of passively listening to lectures, students participate in interactive VR activities that require problem-solving and critical thinking. VR-based platforms contribute to collaborative work to solve math puzzles in a virtual environment. The scholars insist that incorporation of VR tools in the classroom fosters a positive attitude towards mathematics, reducing math anxiety and building confidence (AlGerafi et al., 2023). Obviously, creating a dynamic and interactive learning environment, VR has the potential to make mathematics education more effective and interesting to students.

Despite all the advantages that VR has on learning, it is not yet as widely implemented in classroom practice as might be expected (Rodolico & Hirsu, 2023). These barriers concern high costs, technical challenges, and a lack of infrastructure. The incorporation of VR hardware and software within the educational process can be rather expensive for many educational institutions. Additionally, there are ongoing costs related to maintenance, updates, and training educators to effectively integrate VR into their teaching. Marougkas et al. (2023) mention that the lack of a standardized curriculum for VR-based content and limited research on long-term educational outcomes make it difficult for schools to implement the tools properly.

This study takes forward the suggestion of Campos et al. (2022) that further research on incorporation of VR tool in education is needed to improve the VR-based teaching strategies and integrate VR content into the curriculum of many subjects taught in school. in the context of mathematics education, the research is oriented towards the description of an interplay between in the VR-enhanced learning environment. since this interaction involves communication, feedback, and mutual engagement. The special attention must be paid towards the adapting of teaching strategies to meet the diverse needs of all the students and to create a productive educational experience on the basis of VR technology.

Research Problem

Recently, there has been increasing interest in examining mathematics education and the search for effective teaching technologies to form mathematics competence among school students. It was found that mathematics education was positioned as a universal subject enabling precise measurement, calculation, and analysis (Andrews et al., 2021) as well as transcending culture and values (Hill & Hunter, 2023). Mathematics is essential for a wide range of activities, from everyday tasks like budgeting and cooking to more complex projects such as engineering, medicine, and technology (Abd Algani, 2022). Theoretically, mathematics is a pursuit of knowledge and intellectual challenge. Studying mathematics develops logical reasoning and problem-solving skills among students, fosters their critical thinking and analytical abilities.

Considering the role of mathematics education for students' development, teaching mathematics requires the implementation of innovative technologies within the learning environment to enhance engagement and understanding of educational material (Viberg et al., 2020). Modern technological tools, such as interactive software, online simulations, and educational apps, provide dynamic and visual representations of mathematical concepts and, therefore, make abstract ideas more concrete for students (Su et al., 2022). These technologies also support differentiated learning, enabling instruction to meet the diverse needs of their students and providing the tasks of various levels of difficulty. The findings demonstrate that innovative technologies facilitate a more interactive and collaborative learning environment (Marougkas et al., 2023). Technologies such as virtual classrooms and digital whiteboards create real-time feedback and support, even in remote or hybrid learning environment.

The use of VR in mathematics education creates a 3D learning environment where abstract mathematical ideas can be visualized and manipulated, making them easier for students to understand. The scientific literature focuses on the analysis of VR tools that are integrated in mathematics education (Hossein-Mohand et al., 2021). Some of them include: VR headsets to provide immersive experiences and transport students into the artificial world; educational VR software, such as VR Math or Shapes 3D, contributing to the development of differentiated educational content for teaching mathematical concepts through virtual classrooms, geometric landscapes, and interactive simulations; interactive VR platforms that help to create and share VR content. VR tools contribute to providing a visually rich and interactive environment, where students can visualize and understand abstract concepts. Also, VR encourages students' active learning and emphasizes practical activities, problem-solving, and collaboration to improve their mathematics competence (Cevikbas et al., 2023; Köseoğlu & Türkmen, 2023).

Certain scholars indicate that active learning is oriented towards the implementation of interplay between school teachers and students (Zeinstra et al., 2023). It refers to the dynamic interaction between the participants of the learning process fostering an environment where learners are actively engaged. According to recent findings, productive interplay in the classroom enhances understanding of mathematical concepts through discussions, problem-solving activities, and collaborative tasks (McLure et al., 2023). It develops critical thinking, fosters a collaborative learning environment where students work together to solve problems and explore concepts, and increases students' motivation (Lv et al., 2022). Obviously, an interplay is a vital component of active learning in mathematics. It contributes to a dynamic and supportive learning environment when teaching mathematics in school.

The special attention is paid towards the implementation of interplay between school teachers and students in the context of using digital technologies, particularly AI-driven instruments and VR tools (Grubaugh et al., 2023). Alam and Mohanty (2023) state that interactive demonstrations in real-time are effective to enhance an interplay between teachers and students. Some scholars describe collaborative learning as a method making students to work together in the VR-enhanced environment to complete tasks, solve problems, and explore mathematical concepts (Xiao et al., 2023). A number of studies revealed the use of problem-based learning and scenario-based learning to find solutions within the virtual environment on the basis of their knowledge and skills (Cevikbas et al., 2023). Flipped classroom technology is applied to explore VR content independently and to organize in-class discussions (Jong, 2023). The findings show that an interplay can be implemented through role-play, gamification, and simulations as well (Loureiro et al., 2021). Besides, VR tools are effective to conduct real-time assessments (Hossein-Mohand et al., 2021).

On the basis of the literature reviewed for this research, it becomes clear that an interplay between school teachers and students in the VR-enhanced environment is important because it significantly fosters active engagement, creates immediate feedback, and personalized support. This dynamic interaction helps students better understand complex concepts, stay motivated, and develop critical thinking skills. It is essential to explain the role of interplay between school teachers and students in mathematics education as it promotes a more collaborative, responsive, and effective learning environment and leads to improved students' outcomes.

Research Focus

The description of the peculiarities of an interplay between school teachers and students in VR when studying mathematics contributes to a deeper understanding of how immersive technology is used to enhance the learning process. The pedagogical analysis of the specific interactions that occur in the VR-enhanced environment will help to identify the unique benefits and challenges associated with the implementation of an interplay in the mathematics classroom (Hossein-Mohand et al., 2021; Loureiro et al., 2021). Besides, it is necessary to focus on how teachers can effectively support students when VR tools are incorporated in the lessons or during self-guided work. Some findings demonstrate that the examination of these interactions help to develop the best teaching practices for the effective use of VR in mathematics education (Su et al., 2022). As VR technology becomes more widespread in the school classrooms, it is necessary to provide teachers with the knowledge on evidence-based strategies to enhance the efficiency of the educational process and improve mathematics competence among students (Çakıroğlu et al., 2023). In addition, this research can orient towards the designing of the optimal model of interplay between school teachers and students to update the existing curriculum and to maximize its educational benefits through VR tools. Therefore, investigating these peculiarities in detail provides the opportunities for teachers to improve the teaching practices and increase students' outcomes with the use of innovative technology. The special attention must be paid towards the application of effective teaching methods in the VR-enhanced environment.

Research Aim and Research Questions

The research aim is to describe an interplay between school teachers and students in VR when studying mathematics and to reveal its peculiarities in order to maximize the VR-based environment.

This study seeks to investigate the following research questions:

1) What models of interplay between school teachers and students are applied in VR when studying mathematics?

2) What methodical, organizational, technical, and psychological peculiarities affect the implementation of interplay between school teachers and students?

3) What teaching methods enhance the productivity of an interplay between school teachers and students in VR when studying mathematics?

4) What are the requirements to teachers' training course on the organization of productive interplay between school teachers and students in VR?

Literature Review

An interplay between teachers and students usually refers to the dynamic exchange of ideas, feedback, and support that occurs during the educational process (Zeinstra et al., 2023). This interaction is realized by means of active engagement of students in dialogue, discussions, problem-solving activities, and scenario-based learning (McLure et al., 2023). Some findings indicate that such interplay involves teachers adapting their instructional strategies based on real-time students' responses (Ong & Quek, 2023). Besides, an interplay between teachers and students is described as the mutual influence between the participants of the educational process when teachers' instructional methods are selected to shape students' engagement and understanding of the educational material (Wang, 2023; Zhao, 2022).

Productive interplay between school teachers and students is based on several requirements. They, firstly, relate to positive communication (McLure et al., 2023). Teachers must provide clear instructions, while students should actively participate in the educational process. Secondly, mutual respect is necessary since pedagogical interactions are based in empathy to understand students' emotions and perspectives (Ong & Quek, 2023). Thirdly, Zeinstra et al. (2023) noted that flexibility plays a significant role in maintaining productive interplay when studying mathematics. Teachers need to be responsive to students' needs, adjusting their methods based on real-time feedback and the diverse learning styles present in the classroom.

And fourthly, productive interplay requires the use of collaborative and cooperative approaches to teaching and so students participate in group work and interactive projects (Xiao et al., 2023).

An interplay between school teachers and students in VR when studying mathematics can be implemented through different models describing various approaches to facilitating interactions and engagement in the educational process. The analysis of recent investigations on the topic enabled to differentiate the following: collaborative learning model, interactive model, student-centered model, flipped classroom model, and peer learning model. Collaborative learning model emphasizes the importance of group work in the educational process (Sun et al., 2022). Students work together to solve problems, complete projects, or explore mathematics concepts, with teachers facilitating and supporting group activities. Interactive model focuses on dynamic interactions between teachers and students and involves immediate feedback, discussions, and adaptive teaching practices (Strauß & Rummel, 2020; Yin & Tsai, 2021). Student-centered model is oriented towards students' needs, interests, and learning styles in the educational process (Dong et al., 2019). Here, teachers act as facilitators who provide VR materials and deliver full support within the educational process. At the same time, flipped classroom model occurs when students engage with new content independently through videos or readings and the class time is used for interactive activities, discussions, and problem-solving tasks to improve mathematics competence (Jong, 2023). Peer learning model is closely connected to filliped classroom meaning that students share knowledge and work together on educational tasks (Serin, 2020).

The pedagogical literature demonstrated that an interplay between school teachers and students in VR when studying mathematics involves various peculiarities that can be divided into methodical, organizational, technical, and psychological (Campos et al., 2022; Zeinstra et al., 2023; Zhao, 2022). Methodical peculiarities deal with the specific instructional strategies, approaches, and techniques used to deliver the educational material. According to Allcoat et al. (2021), methodical approaches include designing VR scenarios, introduction of methods for active learning, such as simulation-based activities or interactive problem-solving tasks. Organizational peculiarities relate to classroom management and maintenance of positive group dynamics contributing to formation of mathematics competence among students significantly (Du et al., 2022; Marder et al., 2023). Obviously, technical approach is decisive when an interplay is implemented in the VR-enhanced environment. It requires high-quality VR equipment and software integrated with other educational technologies, such as Learning Management Systems (LMS) or assessment tools (Zhao et al., 2023). Some findings stress that, since VR can be a heavy load for students from cognitive or emotional side, teachers must address to psychological approaches and consider how virtual interactions affect students' collaboration, communication, and peer relationships (Alam & Mohanty, 2023).

In this context, it was found that enhancing the productivity of interplay between school teachers and students in VR when studying mathematics is achieved through certain teaching methods (Widiyatmoko et al., 2023). Rodríguez et al. (2021) declare that VR creates dynamic visualizations of mathematical concepts such as geometric shapes, algebraic functions, and calculus graphs. Besides, virtual manipulatives, like 3D objects, encourage students to explore mathematical ideas, making learning more engaging. Some findings focus on the incorporation of game elements into the VR-enhanced environment to motivate students (Hidajat, 2023; Loureiro et al., 2021). A number of works describe the organization of personalized learning on the basis of VR (AlGerafi et al., 2023). Gligorea et al. (2023) insist that the implementation of adaptive learning algorithms in VR adjusts the difficulty and type of content based on the student's performance. As a result, an interplay between school teachers and students becomes more productive and necessary practical skills are formed. Some studies are devoted to the use of VR for assessment in mathematics education that offers innovative techniques to evaluate students' understanding and skills (Cabero-Almenara et al., 2021; Zhao et al., 2023).

Additionally, the comparative analysis proves that the approaches to implement VR for teaching mathematics in schools varies across countries, influenced by factors such as technological infrastructure, educational policies, and funding. For example, in the United States, the special attention is paid towards enhancing STEM education, including mathematics (Kocabas et al., 2020; Stohlmann, 2020). VR tools are integrated into the curriculum to provide immersive mathematics lessons (Roehrig et al., 2021). Some works of South Korean scholars are devoted to the introduction of VR labs where students can explore mathematical concepts through interactive simulations and virtual manipulatives (Shin et al., 2019). Besides, the findings shows that Finish schools focus on innovative pedagogical approaches and cross-disciplinary projects where mathematics is integrated with subjects like science and art (Lehtonen et al., 2021; Rötkönen et al., 2019). The Chinese government has launched several initiatives to promote the use of advanced technologies, including VR, in school education (Ren et al., 2022). It is worth mentioning that local high-tech companies collaborate with educational establishments to develop VR educational content specifically designed for the Chinese curriculum (Lan, 2019). This content often includes interactive mathematics lessons and virtual trips. And there is an interesting example of Australian schools where innovative classroom models are adopted. According to George-Williams et al. (2020), these models use virtual mathematics labs and interactive problem-solving sessions.

To incorporate VR tools in the mathematics classroom, teachers should undergo advanced training because it equips them with the necessary skills and knowledge to use this technology effectively. In the work of Çakıroğlu et al. (2023) it is mentioned that advanced training ensures that school are proficient in using VR, designing effective VR-based lessons, managing virtual classrooms. It also prepares them to create personalized and student-centered learning environments. Describing the training course Silva-Díaz et al. (2023) state that it includes practical sessions where teachers explore virtual environments and the exercises to create interactive mathematics lessons. Other findings focus on the development of teachers' skills in facilitating student-centered learning and fostering an interactive learning environment on the basis of VR (Rodolico & Hirsu, 2023). Regarding this, the investigation of the peculiarities of an interplay between school teachers and students in VR when studying mathematics requires the special pedagogical analysis to describe the effective models of an interplay implemented in the mathematics classroom and to maximize the use of teaching methods when VR tools are incorporated within the educational process.

Materials and Methods

To study the use of VR tools in the mathematics classroom the research was carried out on the basis of observation methodology involving systematical watching, recording, and analyzing the interactions between teachers, students, and VR technologies in the learning environment. Through observation, researchers were able to gather the detailed qualitative data on the dynamics of VR tool integration and the peculiarities of an interplay between school teachers and students when studying mathematics. The data collected can revealed the models of an interplay, the teaching methods applied and the gaps within the teachers' readiness to use VR tools.

In this context, the theoretical framework for observation methodology incorporated the elements of the Theory of Planned Behaviour (TPB) to understand the acceptance of VR tools by both teachers and students. It concerned the following aspects: (1) attitudes toward the behaviour in the classroom showing the degree to which the participants of the educational process have a favorable or unfavorable evaluation of using the VR tool for teaching mathematics; subjective norms assessing how the expectations and opinions of school teachers and students affect the use of VR in the classroom and change the peculiarities of an interplay when studying mathematics; and perceived behavioural control oriented towards the exploration how school teachers and students perceive their ability to effectively use VR tools and build a productive interplay in the mathematics classroom.

Sample and Participants

The research, organized between September and November, 2023, involved the population of 34 school teachers from five secondary schools. The participants were full-time and part-time mathematics teachers who have undergone the advanced training on using VR technology in the mathematics classroom and were involved in the development of innovative mathematics courseware using VR educational material. Regarding the professional experience, 8 teachers (23,5%) worked at the secondary school for 5 years; 11 teachers (32,4%) – 6-10 years; 13 teachers (38,2%) – 11-15 years; and 2 teachers (5,9%) were employed over than 15 years. 21 participants (61,7%) conducted only regular classes described in the school curriculum. 13 teachers (38,3%) were involved in extra-curriculum activities at the educational institution: mathematics clubs, mathematics competitions, publication of mathematics journals, and mathematics camps. All the participants were informed about the procedures of research and distributed the observation form in advance to consider all the aspects of VR-enhanced environment.

Instruments and Procedures

To collect the data, the observation form was developed and distributed among the participants of the research. It included clearly defined sections to capture basic information such as the date, time, and students involved. Essential components include checklists to assess students' engagement, teachers' facilitation, and the functionality of the VR tools through interplay between school teachers and students. Besides, the special attention was paid towards the qualitative notes on observed interactions and any technical issues. The form also incorporated sections for immediate feedback from both students and teachers, enabling a quick assessment of their perceptions. Table 1 shows the observation form to study the peculiarities of an interplay between school teachers and students in VR when studying mathematics.

Table 1

The Observation Form Used in the Research

<table>
<tr><td colspan="3">We appreciate your cooperation in providing honest feedback about today's use of VR tools in the mathematics classroom and describing the peculiarities of an interplay between teachers and students. Your responses are important for evaluating the effectiveness of these tools and improving their integration into the mathematics lessons on the basis of productive interplay within the learning environment. Please, be as specific and objective as possible.</td></tr>
<tr><td colspan="3">General information</td></tr>
<tr><td>Indicate the following:
1) Date and time
2) Observer's name
3) Classroom
4) Grade level
5) Number of students
6) Teachers' name</td><td colspan="2">Indicate the general information here as it is required.</td></tr>
<tr><td colspan="3">Teacher's behaviour</td></tr>
<tr><td colspan="2">Evaluate the following:
1) Communication
2) Use of teaching methods to engage students
3) Possibility to provide timely and specific feedback
4) Encouragement of self-assessment
5) Classroom management</td><td>Rate the teacher's behaviour according to 5-point scale where: 5 points mean very good, 4 – good, 3 – average, 2 – poor, and 1 – insufficient.</td></tr>
<tr><td colspan="3">Students' engagement</td></tr>
<tr><td colspan="2">Answer the following questions:
1) Was the participation active?</td><td>Answer the following</td></tr>
</table>

2) Did students ask questions feely? 3) Were students engaged in collaborative tasks? 4) Did students show attentiveness and focus during the lesson? 5) Did students demonstrate interest to mathematics concept? 6) Did students collaborate effectively in group work? 7) Did students respond positively to teacher' feedback? 8) Did students were familiar with VR tools?	questions with **yes** or **no**.
Functionality of VR tools	
Evaluate the functionality of VR according to the following statements: 1) VR interface was intuitive for students. 2) VR tools were reliable during the use. 3) Some technical issues with the VR tools affected the delivery of educational material. 4) VR tools were effective in visualizing mathematical concepts. 5) VR system was responsive to user's inputs, such as hand movements, controller actions. 6) VR tool provided positive communication between participants. 7) VR tool facilitated teacher-student interaction during lessons effectively. 8) It was easy for teachers to guide and monitor students' activities within the VR-enhanced environment. 9) VR tools allowed teachers to adapt the educational content to meet individual students' needs. 10) VR tool supported collaborative work among students during mathematics activities. 11) VR tool facilitated communication between students and teachers during complex problem-solving tasks. 12) Students were satisfied with the level of support provided by teachers while using the VR tools.	Rate the statements according to 5-point scale where: 5 points mean absolutely true statement, 4 – partially true, 3 – sometimes true, 2 – rarely true, and 1 – false statement.
Classroom environment	
Provide the detailed answers to the following questions: 1) How does arrangement of seating facilitate interaction and collaboration?	Provide the detailed answers to the open-ended questions. Describe the physical setting of the classroom, the teaching methods used, and the

2) How were the educational materials distributed to students? 3) Were visual aids used in the classroom? 4) How were VR tools incorporated in the educational process? 5) Was classroom atmosphere supportive?	principles how VR tools were incorporated in the educational process.
Recommendations	
Here, indicate the recommendations to improve the teacher's activities in the mathematics classroom to implement a productive interplay between school teachers and students in VR.	
Thank you for your participation and feedback. Your input is valuable for enhancing the use of VR tools in our educational practices.	

Source: Author's development.

Data Analysis

The data analysis involved the examination of the collected data to derive the accurate conclusions. The initial step in data analysis is data organization, where raw observation forms were structured into manageable databases. This involved categorizing qualitative and quantitative data, ensuring that all the research questions were answered. For quantitative data, the descriptive statistics methods were used. Qualitative data was analyzed on the basis of the content analysis to identify the recurring themes, patterns, and significant observations within the data. Also, the correlation analysis was applied to examine the multiple factors of a productive interplay between school teachers and students in VR when studying mathematics. Additionally, qualitative data was interpreted using the coding techniques to draw the conclusions using the open-ended responses. The comparison of the data across different grade levels or groups contributed to understanding the impact and effectiveness of the VR tools in the mathematics classroom.

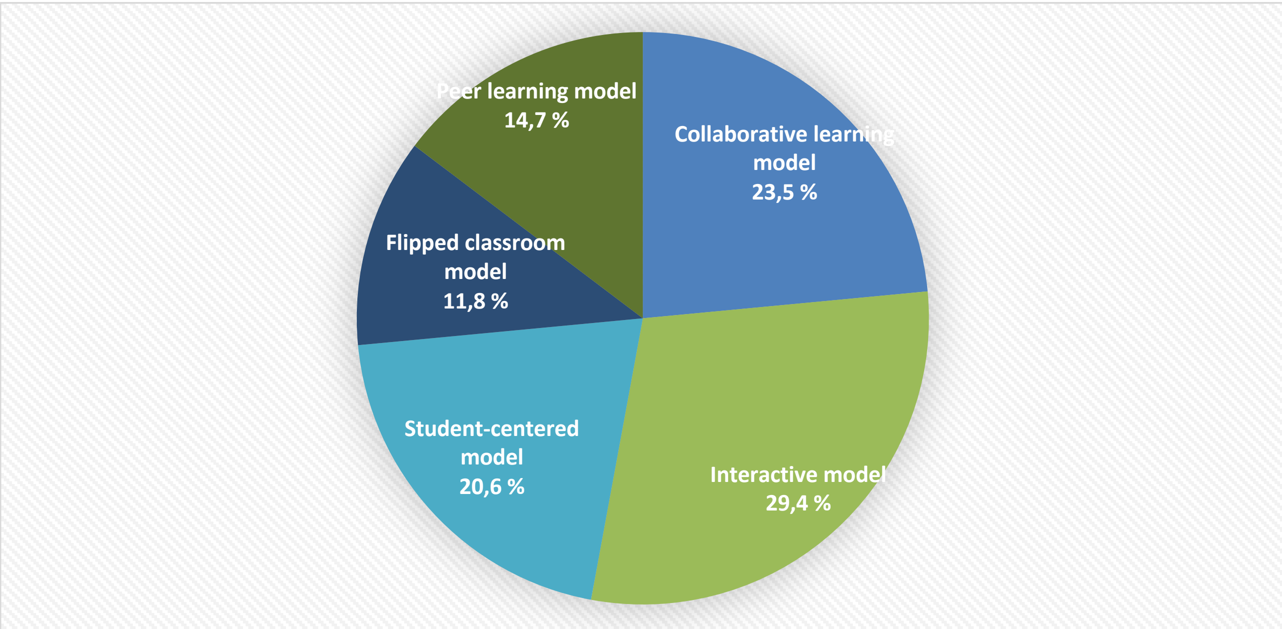
Results

Models of an Interplay Between School Teachers and Students Applied in VR when Studying Mathematics

The findings showed that five models of an interplay between school teachers and students in VR when studying mathematics were applied. They were the following: collaborative learning model, interactive model, student-centered model, flipped classroom model, and peer learning model. The observations demonstrated that interactive model is considered to be most efficient since the majority of teachers (29,4 %) emphasized its advantages in the VR-enhanced environment. Thus, according to mathematics teachers, the use of interactive model contributed to building a productive interplay in VR since it brings several advantages. They include: enhanced students' engagement and motivation; immediate feedback; the possibility to organize personalized learning; establishment of positive communication between the participants of the educational process; and the creation of a safe space for students to experiment and explore mathematical concepts without the fear of making irreversible mistakes. In interactive learning environment teachers create simulations and scenarios that challenge students to think critically and apply their knowledge in practical context. Figure 1 shows the analysis of teachers' preferences on using the models of an interplay between school teachers and students in VR when studying mathematics.

Figure 1

The Use of Models of an Interplay Between School Teachers and Students



Source: Author's development.

Methodical, Organizational, Technical, and Psychological Peculiarities Affecting the Implementation of Interplay Between School Teachers and Students

The findings showed that an interplay between school teachers and students in VR when studying mathematics is affected by methodical, organizational, technical, and psychological peculiarities. The analysis of observation forms demonstrated that methodical peculiarities include clear learning objectives, user-friendly interface, interactive content, real-time feedback, collaboration tools, VR-based assessments, differentiated instruction, aligning VR activities with the existing mathematics curriculum, and effective strategies for classroom management. At the same time, organizational peculiarities relate to the introduction of teachers' professional development, scheduling flexibility, the use of safety protocols, data privacy, collaborative planning, the implementation of pilot programs, accessibility of VR tools to all students. Analyzing technical peculiarities it was found that they concern the following: reliable Internet connectivity, integration of VR tools with the existing educational software and platforms, content relevance, selection of interactive VR tools, high-performance computing. In addition, psychological peculiarities include learning motivation among students, comfort level, cognitive load, sense of presence of students during the mathematics lessons, students' attention, emotional load, and positive attitude towards technology. The survey proves that the combination of methodical, organizational, technical, and psychological peculiarities contributes to the creation of VR-enhanced environment in the mathematics classroom and form mathematics competence among students through an interplay. Table 2 presents the peculiarities affecting the implementation of interplay between school teachers and students in VR.

Table 2

The Peculiarities Affecting the Implementation of Interplay Between School Teachers and Students

Peculiarity	Number of participants (%)				
	Very significantly	Significantly	Average effect	Slightly	No effect
Methodical peculiarities					
Clear learning objectives	14,7%	41,2%	29,4%	8,8%	5,9%
User-friendly interface	17,6%	32,4%	32,4%	8,8%	8,8%
Interactive content	20,6%	47,1%	17,6%	11,8%	2,9%
Real-time feedback	8,8%	35,3%	41,2%	14,7%	0,0%
Use of collaboration tools	23,5%	38,2%	29,4%	5,9%	2,9%
VR activities including formative and summative assessments	8,8%	35,3%	32,4%	23,5%	0,0%
Differentiated instruction	14,7%	44,1%	35,3%	5,9%	0,0%
Aligning VR activities with the existing mathematics curriculum	8,8%	50,0%	32,4%	5,9%	2,9%
Effective strategies for classroom management	14,7%	47,0%	32,4%	5,9%	0,0%

Organizational peculiarities					
Teachers' professional development	52,9%	35,3%	11,8%	0,0%	0,0%
Scheduling flexibility	8,8%	29,4%	47,1%	8,8%	5,9%
Safety protocols	14,7%	44,1%	29,4%	11,8%	0,0%
Data privacy	17,6%	47,1%	26,5%	8,8%	0,0%
Collaborative planning among teachers, administrators, and IT staff	5,9%	32,3%	50,0%	5,9%	5,9%
Use of pilot programs	2,9%	26,5%	55,9%	11,8%	2,9%
Accessibility of VR tools and activities to all students	29,4%	70,6%	0,0%	0,0%	0,0%
Technical peculiarities					
Reliable Internet connectivity	26,5%	58,8%	14,7%	0,0%	0,0%
Integration of VR tools with the existing educational software and platforms	14,7%	41,2%	44,1%	0,0%	0,0%
Content relevance	20,6%	35,3%	38,2%	5,9%	0,0%
Selection of VR tools offering high levels of interactivity	23,5%	38,3%	35,3%	2,9%	0,0%
High-performance computing	17,7%	38,2%	38,2%	5,9%	0,0%
Psychological peculiarities					
Learning motivation	8,8%	38,2%	41,2%	5,9%	5,9
Comfort level	2,9%	26,5%	53,0%	14,7%	2,9%
Cognitive load	5,9%	29,3%	47,1%	11,8%	5,9%
Sense of presence	2,9%	35,4%	29,4%	23,5%	8,8%
Attention	14,7%	44,1%	29,4%	11,8%	0,0%
Emotional load	2,9%	29,5%	47,1%	17,6%	2,9%
Positive attitude towards technology	8,8%	38,2%	44,2%	8,8%	0,0%

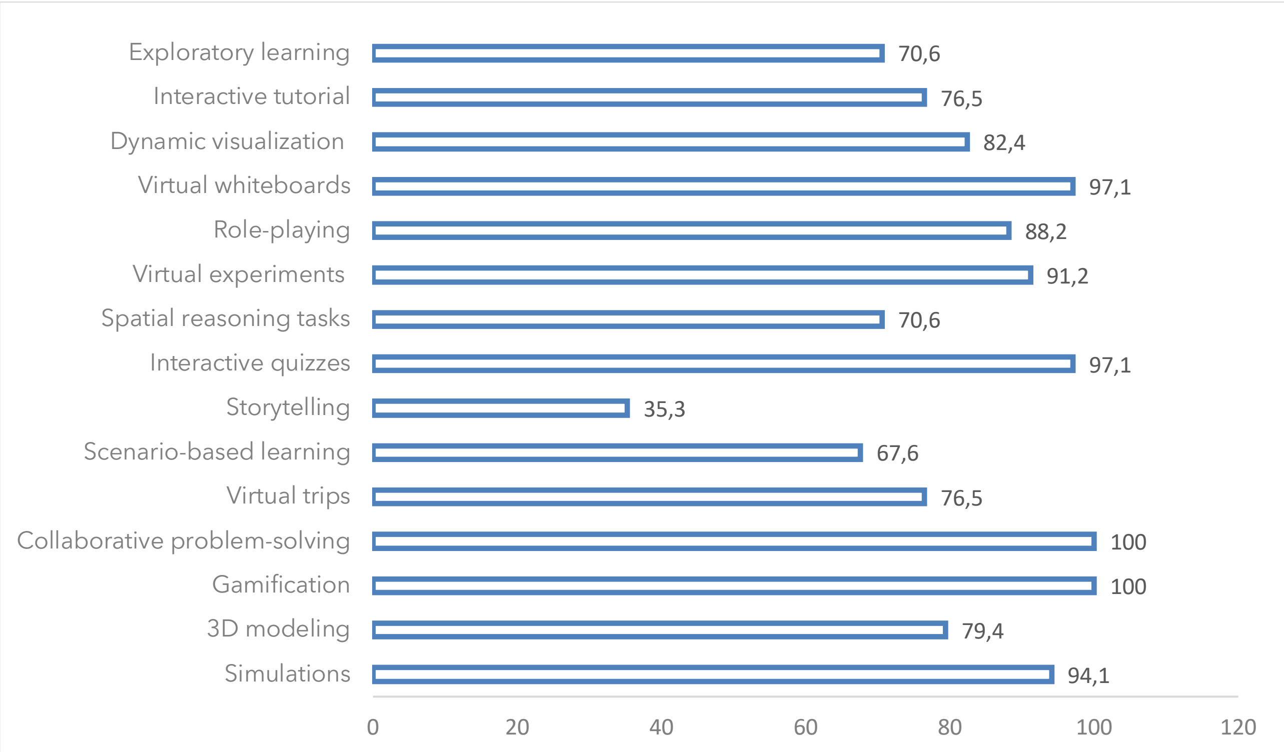
Source: Author's development.

Teaching Methods Enhancing the Productivity of an Interplay Between School Teachers and Students in VR when Studying Mathematics

Teaching methods are found to be important in enhancing the productivity of interplay between school teachers and students in VR when studying mathematics because they provide the strategies needed to apply the technology effectively. The findings demonstrated that a number of teaching methods are used in the mathematics classroom where VR tools are incorporated. Collaborative problem-solving activities and gamification are considered to be the most effective by mathematics teachers and they are used by 100 % of participants. Also, interactive quizzes and virtual whiteboards are widely implemented since 97,1 % of mathematics classrooms incorporated these teaching methods. Other methods include simulations (94,1 %), virtual experiments (91,7 %), role-playing (88,2 %), and dynamic visualization (82,4 %). The observations demonstrated that there are other teaching methods used in VR when studying mathematics and they proved to have a significant impact upon productivity of interplay between school teachers and students, but they are used less often. They are the following: scenario-based learning (67,6 %), exploratory learning and spatial reasoning tasks (70,6 %), interactive tutorial and virtual trips (76,5 %). It is important to mention that only 35,3 % of teachers use storytelling because it can oversimplify the complex mathematical concepts, and leading to misunderstanding of educational material. Additionally, some teachers insisted that focusing too much on narrative elements distracts students from the mathematical objectives. Figure 2 shows teaching methods enhancing the productivity of an interplay between school teachers and students in VR when studying mathematics.

Figure 2

Teaching Methods Enhancing the Productivity of an Interplay



Source: Author's development.

The Requirements to Teachers' Training Course on the Organization of Productive Interplay Between School Teachers and Students in VR

The research proved that the organization of productive interplay between school teachers and students in VR when studying mathematics require the introduction of additional teachers' training. The survey participants were asked to provide recommendations on improvement of VR-enhanced environment of the mathematics classroom and most answers (88,1 %) concerned the necessity to implement the course on the application of VR tools for teaching mathematics. It was found that the course is essential for several reasons. Firstly, it will equip educators with the necessary technical skills to effectively use VR technology. Secondly, these courses will provide pedagogical strategies helping teachers design and implement interactive learning activities. Thirdly, training will help to understand the methodical, organizational, technical, and psychological peculiarities of an interplay between school teachers and students and will contribute to classroom management significantly. definitely, well-trained teachers will maximize the educational benefits of VR tools, enhancing students' engagement, motivation, and learning outcomes in mathematics.

Based on the analysis of observation forms describing the gaps in the creation of VR-enhanced environment when studying mathematics, it was found that one ECTS teachers' training course on the organization of productive interplay between school teachers and students in VR should be introduced. Considering the teachers' perceptions of the role of VR tools in mathematics education and productivity of an interplay between school teachers and students in the mathematics classroom, the course should include the following topics: Introduction to VR in mathematics education; Practical training on using VR hardware and software; Mathematics content in VR; Designing VR-based mathematics lessons; Interactive simulations for mathematics; Gamification techniques in VR; Collaborative learning in VR; Problem-solving activities; Peer interactions in VR; Providing feedback; Assessment and evaluation in VR; Differentiated instruction in VR. Table 4 shows the distribution of hours through the teachers' training course.

Table 3

The Structure of Teachers' Training Course

No	Topic	Hours required
1.	Introduction to VR in mathematics education	1
2.	Practical training on using VR hardware and software	5
3.	Mathematics content in VR	6
4.	Designing VR-based mathematics lessons	4
5.	Interactive simulations for mathematics	2
6.	Gamification Techniques in VR	2

7.	Collaborative Learning in VR	2
8.	Problem-solving activities	2
9.	Peer interactions in VR	2
10.	Providing feedback	2
11.	Assessment and evaluation in VR	2
12.	Differentiated instruction in VR	2
	TOTALLY	**30**

Source: Author's development.

Therefore, a productive interplay between school teachers and students is important in VR when studying mathematics because it fosters an interactive and dynamic learning environment resulted in enhanced comprehension and retention of complex mathematics concepts. In the VR-enhanced environment, teachers monitor students' progress, provide immediate support, and tailor instructions to individual learning needs through simulations and visualizations. This active engagement increases students' motivation in the subject as well. The investigation of models of productive interplay when studying mathematics, selection of effective teaching methods, and analysis of methodical, organizational, technical and psychological peculiarities of an interplay between school teachers and students in VR may enhance the efficiency of contemporary mathematics education in school. Additionally, the incorporation of course on the organization of productive interplay between school teachers and students in VR into teachers' professional development program will contribute to formation of readiness of mathematics teachers to use innovative technology effectively in the classroom.

Discussion

The findings revealed the importance of the investigations devoted to an interplay between school teachers and students in VR when studying mathematics. A number of works demonstrate the enhancement of efficiency of learning environment through positive interaction between the participants of the educational process (Xiao et al., 2023; Zeinstra et al., 2023). Considering the fact that interplay refers to the dynamic interaction between teachers and students through dialogue, discussions, problem-solving activities, games, and simulations (Campos et al., 2022; McLure et al., 2023), it requires the implementation of specific classroom management patterns. The literature review revealed that an interplay between school teachers and students in VR when studying mathematics is realized through different models describing various approaches to facilitating interactions and engagement in the educational process, such as collaborative learning model (Sun et al., 2022), interactive model (Strauß & Rummel, 2020; Yin & Tsai, 2021), student-centered model (Dong et al., 2019), flipped classroom model (Jong, 2023), and peer learning model (Serin, 2020). All of them have both strength and weaknesses and can be introduced on the basis of learning purpose, infrastructure development, and students' learning styles.

According to the observation research, these five models of an interplay between school teachers and students are applied when studying mathematics. The participants explained that interactive model is most efficient since it enables to maximize the potentials of the VR-enhanced environment. it was found that the use of interactive model contributed to building a productive interplay in VR that oriented towards enhancement of students' engagement and motivation, immediate feedback. Also, the model provides the possibility to organize personalized learning, establishes the positive communication between school teachers and students. Additionally, interactive model helps to create a safe space for students to experiment and explore mathematical concepts. It is advantageous for incorporation of simulation-based learning, and scenarios that improve students' practical skills significantly as well as increase the interest to mathematics concepts.

The special attention was paid towards the peculiarities of an interplay between school teachers and students in VR when studying mathematics. It was found that these peculiarities include methodical, organizational, technical, and psychological ones (Campos et al., 2022; Zeinstra et al., 2023; Zhao, 2022). The survey proved that an interplay between school teachers and students in VR when studying mathematics is affected by methodical, organizational, technical, and psychological peculiarities as well. The classroom observations enabled the researchers to outline the peculiarities in details and further to use the data for the maintenance of productive interplay between school teachers and students. Thus, according to the survey participants, methodical peculiarities include clarification of learning objectives, use of user-friendly interface, introduction of interactive content, real-time feedback. Also, they relate to the application of effective collaboration tools, VR-based assessments, and differentiated instruction. Organizational peculiarities concern teachers' professional development, scheduling flexibility, safety protocols, data privacy, and collaborative planning. Importantly, accessibility of VR tools to all students is necessary when planning the lesson on the base of VR tools. Technical peculiarities included reliable Internet connectivity, integration of VR tools with the existing educational software and platforms, content relevance, selection of interactive VR tools, high-performance computing. Besides, it was proved that psychological peculiarities have a significant impact upon include learning motivation among students, comfort level, cognitive load, sense of presence of students during the mathematics lessons, students' attention, emotional load, and positive attitude towards technology. The survey proves that the combination of methodical, organizational, technical, and psychological peculiarities contributes to the creation of VR-enhanced environment in the mathematics classroom and form mathematics competence among students through an interplay. Table 2 presents the peculiarities affecting the implementation of interplay between school teachers and students in VR.

The research insisted that a productive interplay between school teachers and students in VR when studying mathematics is achieved through certain teaching methods (Widiyatmoko et al., 2023). They included dynamic visualizations of mathematical concepts (Rodríguez et al., 2021), gamification (Hidajat, 2023; Loureiro et al., 2021), and personalized learning on the basis of VR (AlGerafi et al., 2023). Besides, the implementation of adaptive learning algorithms in VR was described by Gligorea et al. (2023) to show the increase of students' learning outcomes by means of VR tools. Some works were devoted to the introduction of innovative assessment approaches in the VR-enhanced learning environment (Cabero-Almenara et al., 2021; Zhao et al., 2023). The role of interactive simulations in studying mathematics was studied by Shin et al. (2019). At the same time, the use of virtual mathematics labs and interactive problem-solving sessions was outlined by George-Williams et al. (2020).

The findings demonstrated that a number of teaching methods are used in the mathematics classroom where VR tools are incorporated. Collaborative problem-solving activities and gamification are considered to be the most effective by mathematics teachers. Also, interactive quizzes and virtual whiteboards are widely implemented. Other methods include simulations, virtual experiments, role-playing, and dynamic visualization. The observations demonstrated that scenario-based learning, exploratory learning and spatial reasoning tasks, interactive tutorial and virtual trips proved to have a significant impact upon productivity of interplay between school teachers and students, but they are used less often. Storytelling is less popular in the mathematics classroom because it can oversimplify the complex mathematical concepts, and leading to misunderstanding of educational material.

It was found that the incorporation of VR tools in the mathematics classroom demands advanced teachers' training to use this technology effectively (Çakıroğlu et al., 2023). The literature suggests that the course should include the following topics: personalized and student-centered learning environments (Zhao et al., 2023), designing effective VR-based lessons, managing virtual classrooms (Çakıroğlu et al., 2023), the creation of interactive mathematics lessons (Silva-Díaz et al., 2023). Based on the analysis of observation forms describing the gaps in the creation of VR-enhanced environment when studying mathematics, the pilot teachers' training course on the organization of productive interplay between school teachers and students in VR was developed. The course related the following topics: Introduction to VR in mathematics education; Practical training on using VR hardware and software; Mathematics content in VR; Designing VR-based mathematics lessons; Interactive simulations for mathematics; Gamification techniques in VR; Collaborative learning in VR; Problem-solving activities; Peer interactions in VR; Providing feedback; Assessment and evaluation in VR; and Differentiated instruction in VR. The findings showed that the implementation of this course into teachers' professional development may enhance the educational process on the basis of VR tools and maintain a productive interplay between school teachers and students when studying mathematics.

Conclusions and Implications

VR aims to simulate the senses as realistically as possible and allows users to explore objects or phenomena virtually in the artificial world. VR has significant educational potentials in creation realistic simulations and environments where students can interact with educational material actively, accommodating various learning styles and needs, and organization of differentiated instruction. VR brings a number of benefits in mathematics education as well. It provides the activities that simplify complex concepts and enhances students' engagement, helps to transform abstract symbols and equations into visual experiences, promotes active learning and increases motivation.

An interplay between teachers and students usually refers to the dynamic exchange of ideas, feedback, and support that occurs during the educational process. This interaction involves teachers adapting their instructional strategies based on real-time students' responses. Productive interplay between school teachers and students is based on positive communication, clear instructions, mutual respect, empathy to understand students' emotions and perspectives, flexibility, and use of collaborative and cooperative approaches to teaching. An interplay between school teachers and students in VR when studying mathematics can be implemented through collaborative learning model, interactive model, student-centered model, flipped classroom model, and peer learning model. Besides, the findings showed that an interplay involves methodical, organizational, technical, and psychological peculiarities affecting its productivity.

Additionally, a productive interplay between school teachers and students in VR when studying mathematics is achieved through certain teaching methods. They included dynamic visualizations of mathematical concepts, gamification, personalized learning on the basis of VR, innovative assessment approaches, interactive simulations the use of virtual mathematics labs and interactive problem-solving sessions. The survey proved the efficiency of collaborative problem-solving activities, gamification, interactive quizzes and virtual whiteboards, simulations, virtual experiments, role-playing, and dynamic visualization for maintenance of a productive interplay between school teachers and students in VR when studying mathematics.

The incorporation of VR tools in the mathematics classroom demands advanced teachers' training to use this technology effectively. The course should include the following topics: personalized and student-centered learning environments, designing effective VR-based lessons, managing virtual classrooms, the creation of interactive mathematics lessons, assessment and evaluation in VR, differentiated instruction. The implementation of this course into teachers' professional development is aimed at the enhancement of mathematics education the basis of VR tools and formation of high level of mathematics competence among students.

The research results proved the importance of an interplay between school teachers and students in VR when studying mathematics and they may have significant implications for the educational practices. First, these findings explain the need for advanced teachers' training programs that focus on the integration of VR technology into the mathematics curriculum. Teachers must be equipped with not only the technical skills to use VR but also the pedagogical strategies to facilitate effective student-teacher interactions within this VR-enhanced environment. The results may be used for the development of virtual session, workshops, or formal training courses on the implementation of VR tool in the mathematics classroom and the maintenance of a productive interactions between school teachers and students. Also, the findings may be used at the institutions of higher education training future mathematics teachers to update their curriculum and form innovative readiness among students. The implications of these research may result in the improvements of school mathematics when VR-based activities and lessons are incorporated. This courseware should include various activities to encourage students' active participation, critical thinking, and problem-solving skills. Considering that an interplay between school teachers and students is importance, the inclusion of effective teaching methods into the lesson plans will probably enhance the educational process and increase the level of mathematics competence among students.

Suggestions for Future Research

Future research devoted to an interplay between school teachers and students in VR when studying mathematics can explore several areas to deepen understanding and enhance educational practices. Firstly, the special attention must be paid towards comparative studies since they serve as an important basis for the maximization of possibilities of an interplay between school teachers and students. Systematical comparison of various models through can reveal the specific strengths and weaknesses of VR-enhanced environment. The comparative analysis can provide valuable information on how VR tools enhance students' engagement, comprehension, and collaboration. Such research can identify the most effective aspects of VR integration into mathematics education and present the best practices for implementing VR in the mathematics classroom, ensuring that the technology helps to maintain a productive interplay between school teachers and students.

Other suggestions relate to the development of advanced teachers' training programs on the interplay between teachers and students in VR when studying mathematics. Investigating how different training components – technical proficiency, VR-based pedagogical strategies, classroom management, and methods for providing real-time feedback – impact the effectiveness of VR-based teaching through the formation of VR competence among mathematics teachers. This research can outline identify the most significant elements of teachers' preparation and improve the process of professional training of future teachers at the institutions of higher education.

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