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Using Technology to Create Simulations that Aid Content Comprehension of Pre-Service Teachers in Karachi

Muhammad Umair Khan[1] (*Corresponding Author*)
Government Elementary College of Education
Hussainabad, Karachi – Pakistan

Zenab Moiz[2]
Government Elementary College of Education
Hussainabad, Karachi – Pakistan

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Abstract

This paper presents a qualitative study on the use of technology to create simulations and other meaningful digital experiences that enhance the content comprehension of pre-service teachers enrolled in a B.Ed. (Hons) program in Karachi, Pakistan. The study focuses on how a mathematics pedagogy course used digital tools for the teaching of mathematical concepts, like GeoGebra, to create interactive simulations to illustrate trigonometric ratios and their relationship to angle measures. It also examines how a social studies pedagogy course used Google Earth and Google Arts & Culture websites to create immersive virtual experiences of historical and geographical concepts. The paper presents the subjective experiences of student-teachers from the aforementioned courses as recipients of this technology-based pedagogy. Student-teachers reported that the simulations, virtual field trips, and other interactive and immersive digital experiences used in their mathematics and social studies pedagogy courses helped them visualise complex ideas and relationships, which strengthened their content comprehension and increased their motivation to learn.

Keywords

Content comprehension

GeoGebra

Google earth

Pre-service teachers

Technology-driven simulations

INTRODUCTION

Subject-matter competence is one of the most important determiners, if not the single most important determiner of success in teaching (Coe et al., 2014). According to Alexander (2010), "What teachers know and how they think shapes, for better or worse, how they teach and how their pupils learn" (p. 28). Given the central importance of teachers' command over the subject matter that they teach, teacher education colleges and training institutes must employ teaching approaches and methods that deepen pre-service teachers' subject-matter knowledge and strengthen their content comprehension before they enter the profession of teaching. While this is true for teachers of all subject areas and grade levels, the focus of this research is the development of subject matter competence of prospective primary and middle-school teachers of mathematics and social studies. Several researchers have identified gaps in prospective primary and secondary school teachers' mathematical content knowledge and their ability to formulate well-reasoned mathematical explanations (Quinn, 1997; Lo, 2020). Similarly, researchers have pointed out deficiencies in pre-service teachers' subject knowledge of geography and their lack of confidence in their ability to teach geography in K-12 classrooms (Rynne & Lambert, 1997). In countries such as Pakistan, this problem is further exacerbated by three additional factors. First, education in Pakistan is faced with a perpetual crisis of quality, especially at the level of school education (Memon, 2007). A natural consequence of this reality is that high-school graduates, including those who would enter teacher education colleges as prospective teachers, would carry content comprehension gaps across all subjects taught during the school years.

Teacher education colleges and other pre-service training institutes would need to fill in these content gaps in addition to teaching student-teachers the skills and dispositions needed to become strong teachers. Second, the profession of teaching does not enjoy the same prestige as the other more sought-after professions such as medicine and engineering hence, teaching does not attract the best talent in the country (Hussain et al., 2018). Third, most pre-service teacher education programs do not adequately prepare prospective teachers for the difficult job of teaching at the K-12 level or to becoming future leaders of change in schools (Rizvi, 2015). As a result, K-12 teachers in Pakistan generally lack in terms of subject matter competence and pedagogical linkages; two vital pillars of successful teaching practice (Hussain & Ali, 2010; Siddiqui et al, 2021).

Objectives

The purpose of this study is to explore the potential of technology in addressing the problem of content

comprehension gaps in prospective teachers by documenting the perceptions of student-teachers experiencing a technology-based pedagogical approach used in two subject area courses of a pre-service teacher education program. While strong content knowledge and depth of understanding are necessary for school teachers from across all subject areas, the focus of this research is prospective teachers' subject matter competence in the areas of mathematics and social studies.

Research Question

This study tends to explore the answer of the following research question:

- How do student-teachers enrolled in mathematics and social studies courses of B.Ed. (Hons) program perceive the efficacy of digital simulations and other meaningful digital experiences in strengthening their subject matter competence?

LITERATURE REVIEW

Evidence suggests that technology, when employed effectively in classrooms, can have a significantly positive impact on students' learning (Dahlstrom et al., 2014; Motiwalla, 2007). This is true for both school children and adult learners (Awidi et al., 2024; Chen et al., 2021; Li et al., 2020; Mou et al., 2021). In mathematics, technology has long been used as a tool to create engaging and meaningful learning experiences. Leveraging the programming environment Scratch to develop computational thinking (Rodríguez-Martínez et al., 2020), incorporating video games and simulations in STEM lessons (Ormsby et al., 2011), and using the computer program The Geometer's Sketchpad to teach high school geometry (Cayton et al., 2017) are just some of the many examples of effective use of technology in mathematics education. The use of calculators is something that does not even get noticed as a powerful use of technology anymore since its use has become widespread. Pertinent to the intervention described in this paper is the use of GeoGebra for teaching geometry, trigonometry, and algebra concepts. Bedada and Machaba (2022) have, for example, studied the effect of the GeoGebra software on Grade 12 students' success in making associations between the representations of trigonometric functions and the interpretation of graphs.

The tool remains underutilized, however, with Yohannes and Chen (2023) suggesting that teachers are not tapping the full potential of GeoGebra's dynamic features that "enable students to comprehend abstract mathematics concepts from elementary schools to higher institutions" (p. 13). Similarly, to teach the different strands (geography, history, current affairs, civics etc.) of the subject of social studies in a holistic and meaningful manner, teachers across different contexts and at different grade levels have employed and recorded the use of several effective ways. Many deploy the creative use of digital immersive tools such as Google Earth and Google Arts & Culture (Hsu et al., 2018; Mejía Ávila et al., 2021; Patterson, 2007). Evidence exists that the dynamic software Google Earth can be used as early as at the preschool level as children start to make sense of the world around them (Danby et al., 2016). Not only does technology help understand social studies content better, but it also has the potential to shape an individual's perception of and attitude towards the subject itself (Erdoğan & Şerefli, 2021).

Technology can also help bridge gaps in content comprehension of pre-service teachers enrolled in teacher education colleges and help them develop the kind of subject-matter competence that is required to become capable practitioners in their future teaching careers (Weinburgh et al., 1997). It is the job of teacher educators to demonstrate effective and meaningful use of technology in teaching to strengthen pre-service teachers' content comprehension as well as build their pedagogical competence (Wright & Wilson, 2009). Several studies have discussed how software such as GeoGebra and Google Earth have been employed in teacher education contexts not only to build content knowledge of student-teacher but also to equip them with technological tools that they can use in their classrooms (Misfeldt & Zacho, 2016; Sherman-Morris et al., 2009). This research paper is focused primarily on the first purpose, that is, the development of student-teacher subject-matter competence. It does, however, discuss the related goal of building student-teachers capacity to employ technology-centric pedagogical approaches as an important implication of this study.

While these examples are indeed encouraging, there is still a long way to go in terms of realizing the full potential of technology in terms of building content comprehension of pre-service teachers enrolled in teacher education colleges and training institutes across Pakistan and the world. Yohannes and Chen (2023) recommend that teacher education programs should make efforts "to ensure that prospective teachers have relevant Technological Pedagogical Content Knowledge (TPCK) in connection with mathematics teaching and learning" (p. 13). The authors of this research contend that a critical first step in the development of prospective teachers' TPCK is to make them experience the efficacy of technology-based pedagogy as learners. Based on the importance of technology in teaching and learning, the authors of this research planned a series of lessons in their respective mathematics and social studies courses to incorporate technological tools relevant to their respective subject areas. The primary objective of this technological intervention was to build the subject-matter competence of student-teachers. An underlying expectation was that student-teachers would be able to appreciate the immense potential of technology to create powerful and engaging lessons at all levels of the educational hierarchy.

METHODOLOGY

This research employed a qualitative analysis methodology in which the data were collected through semi-structured interviews conducted with student-teachers enrolled in mathematics and social studies pedagogy courses. These interviews were conducted after a series of lessons that incorporated technological tools for teaching content knowledge in the courses. Participants for the interviews were chosen using purposive sampling. Data collected from these interviews were thematically analysed, which revealed important insights about subject-matter comprehension of student-teachers and their understanding of creating pedagogical linkages.

The Intervention

In the mathematics pedagogy course, simulations were created using technology tools to help student-teachers visualize and understand complex concepts. This involved utilizing tools such as GeoGebra to develop interactive simulations that allowed student-teachers to explore the dynamic relationship between trigonometric ratios and angle values. By engaging with these simulations, student-teachers were able to grasp mathematical concepts more effectively and develop a deeper understanding of their application.

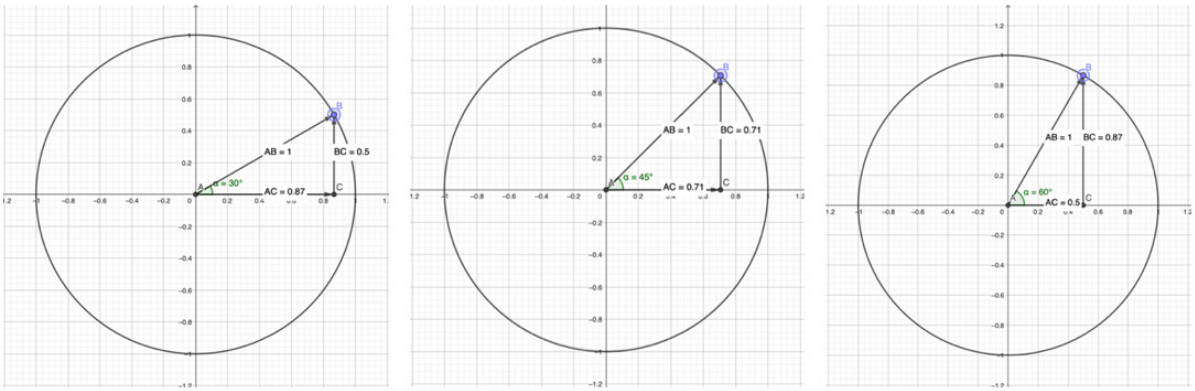

Fig. 1. Snapshots of Different Stages of a Simulation Created Using Geogebra, Illustrating the Values of the Sine and the Cosine of an Angle at Different Angle Measures

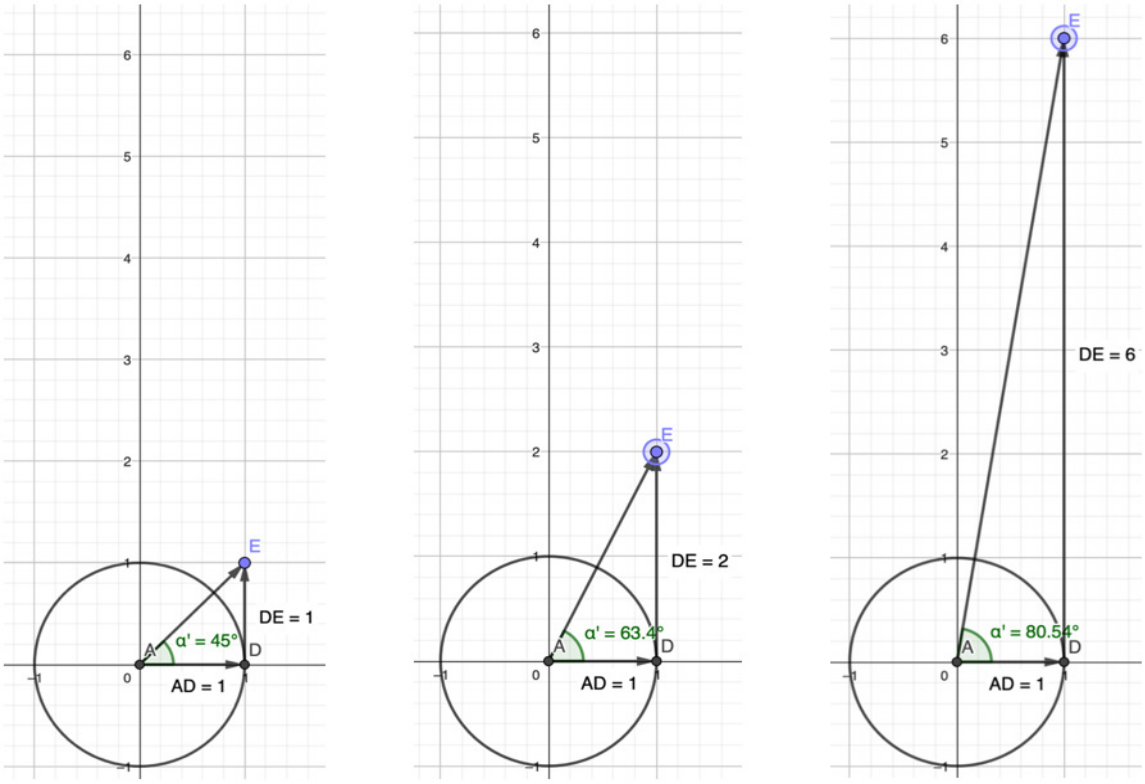

Fig. 2. Snapshots of Different Stages of a Simulation Created Using Geogebra, Illustrating the Values of the Tangent of an Angle at Different Angle Measures

In the social studies pedagogy course, technology was employed to create simulations and immersive digital experiences that facilitated content comprehension. Student-teachers utilized tools such as Google Earth to visualize physical features and their influence on various aspects of human life. Additionally, the integration of resources like the Google Arts & Culture website helped student-teachers establish connections between physical and human geography. Through these simulations, student-teachers gained a more comprehensive understanding of social studies content and its real-world relevance.

Fig. 3. Images of Karachi Coastline and Mangroves Explored Through Google Earth

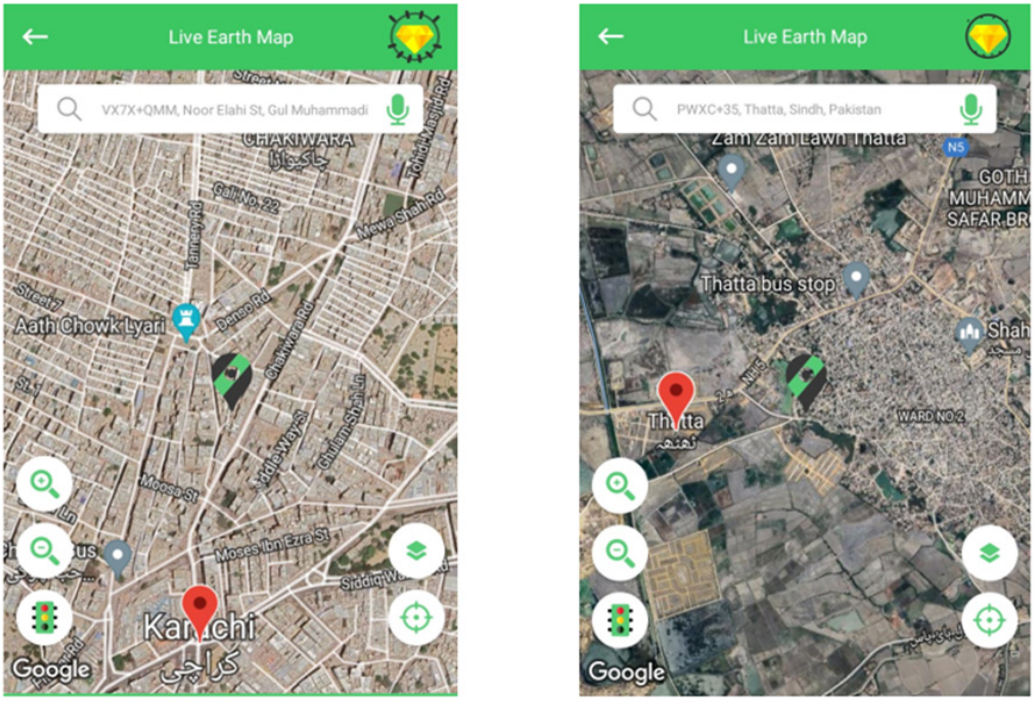

Fig. 4. Live Maps of Karachi and Thatta Illustrating Different Population Densities

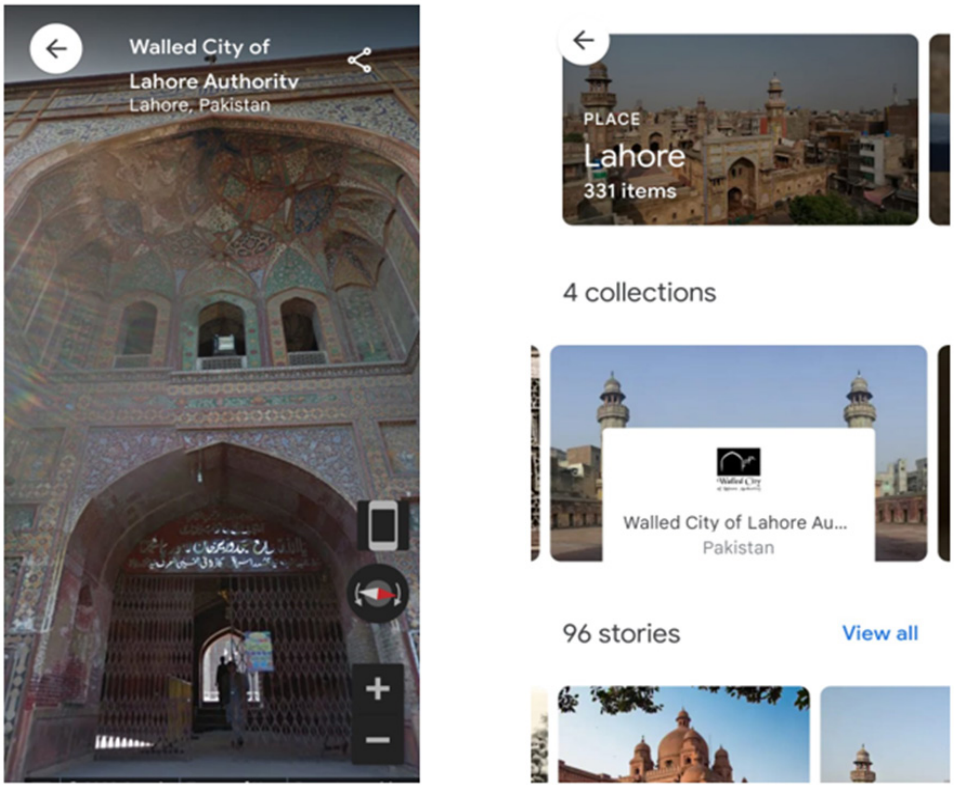

Fig. 5. 360° View of the Walled City of Lahore Taken from Google Arts & Culture Website

Data Collection

Interviews of Student-Teachers

Two student-teachers each from each specialization area (mathematics and social studies) were selected for semi-structured interviews. These interviews were conducted in Urdu and were later translated and paraphrased for analysis. The purpose of these interviews was to gather insights related to student-teachers experience of the technological interventions designed by both instructors. The

interview questions belonged to two categories:

Questions On Content Comprehension

The purpose of these questions was to understand how student-teachers felt about the technological interventions impacting their content comprehension and their experience of learning the associated content in their B.Ed. specialization course compared to their experience of learning the same content during school years. This category of questions pertains to the focus of this research. The list of questions below were the core questions explored during the interviews.

- How would you describe your experience of learning content through technology-based simulations?
- What was particularly great about learning content through technology-based simulations?
- What are some of the ways in which this experience could have been improved?
- How did the experience of learning content through technology-based simulations compare to your prior experience of learning the same content during school years?

Questions On Implications for Teaching Practice

The purpose of these questions was to understand how student-teachers felt the experience of learning content through the technological interventions would impact their ability to teach the same content and if a similar approach to teaching content can be taken in a K-12 classroom. This category of questions pertains to the implications of this study for further research and practice. The questions are listed below (they were adapted for the two specialization subjects):

- What impact, if any, did the learning content through technology-based simulations have on your ability to teach the same content?
- Do you think such an experience can be created in an actual primary/middle-school classroom? What are the potential challenges that you foresee? How can these be overcome?
- Did you want to learn how to create the same simulation/virtual experience by learning more about the software/website on which the simulation/virtual experience was created by your instructor?
- To what extent do you think it is a good idea to teach content using technology-based simulations in a B.Ed. classroom?

RESULTS & FINDINGS

The responses that we received from the four interviewed student-teachers were qualitatively analysed. The following themes emerged from this analysis:

The Importance of Visualization in Learning

The student-teachers interviewed during this research reported that simulations and visual experiences helped them understand concepts such as trigonometric ratios in mathematics and the interconnections between physical and human geography in social studies in greater depth. Pseudonyms have been used for the participants. Khadija reported that it was because of the dynamic models created in GeoGebra that she was able to visualize the changes that happened in trigonometric ratios with changes in the angle measures. For example, how the perpendicular got longer as the base shrunk. She had struggled in the initial few classes on trigonometry in which trigonometric ratios were being explored by looking at static images of right triangles.

While the static drawings provided the imagery needed to visualize trigonometric ratios, they did not help with visualizing the dynamic relationship between angle measures and trigonometric ratios. Like how the sine of an angle increases (the perpendicular grows) and the cosine decreases (the base shrinks) as the angle increases from 0 to 90 degrees. With static drawings, it was not easy to imagine the movement of a point along a circular path and the concomitant changes in its horizontal and vertical

coordinates (the base and the perpendicular of the associated right triangle). The 'onus of imagination' was on the learners. They had to visualize how, for example, the right triangle collapses to become an upright line, indicating the equality of the perpendicular and the hypotenuse (and a sine value of 1), as the angle approaches 90 degrees. The simulations helped them see how this happens in real time. They could observe the movement of a point on a circular path and the concomitant changes in trigonometric ratios. Similarly, Rabia, another interviewee from the math specialization course, reported that she had always struggled conceptualizing how the value of the tangent function approaches an infinitely large value as the angle measure approached 90 degrees. She could not visualize what it meant for a ratio of two lengths to approach infinity. It was only after she saw the simulation that showed the tangential segment of a circle increasing to an infinitely long length as the angle measure approached 90 degrees that she was able to conceptualize the value of the tangent function for an angle of 90 degrees. The simulations aided both student-teachers' imagination and strengthened their understanding.

Sana, a student-teacher from the social studies specialization track, shed light on the importance of visualization in the subject of social studies. She described how her prior experience of learning about topics of geography such as physical features and landscapes was very dull because she was unable to visualize how these physical features looked like. She had never been to places where such physical features were present, and the images that were there in the textbooks were either not related or were blurred or lacked important details such as colour or were not representative enough (e.g., always showing mountains in brown colour). She also gave an example of the topic of population density and how the images present in her textbooks did not illustrate the relationship between population density and area. It was only after she was shown satellite images of densely populated cities on a live earth map on Google Earth during her social studies course at GECE that she was able to truly understand the idea of population density. By comparing night-time satellite images of Karachi and Thatta, she was able to distinguish high-density cities from low-density cities and hence understand the idea of population density in its true sense. Sana reported that the images that she had earlier seen in her school textbooks did not help her grasp this idea because those images were very generic (e.g., the image of an overly crowded marketplace or a public bus), which does not help young children distinguish cities with high population densities from those with lower densities.

Similarly, Bakhtawar reported that since she had never visited Lahore, she had never been able to relate to the descriptions she had read about that city throughout school years. This changed when during her B.Ed. social studies course, she was assigned the task of creating a virtual field trip to Lahore for her fellow student-teachers using Google Arts & Culture. She had always imagined Lahore in the image of Karachi, so she was pleasantly surprised to see that Lahore had a distinctly different architecture and lifestyle from Karachi. Most striking for her was the difference between Old Karachi's British-style architecture and Old Lahore's Indo-Persian Mughal architecture. In her words, it was as if she was visiting Lahore for the first time.

Rote Memorization versus Meaningful Exploration

Student-teachers interviewed during this research reported that their instructors' pedagogical approach, which included the integration of simulations and visual experiences, helped them develop a deeper understanding of the topics that they had studied in a very superficial manner during school years. Both Khadija and Rabia reported that, during high school, they had learned about trigonometric ratios in a very abstract way. They were made to memorize the formulas for calculating trigonometric ratios, but they were never made to explore these ratios in a meaningful way. Both reported that they had relied heavily on the famous mnemonic 'Some People Have Curly Brown Hair Through Proper Brushing' for retaining the formulas for calculating trigonometric ratios. They knew how to manipulate these formulas to calculate one value if the other values were known, but they could not see the point of doing these calculations. In stark contrast to this, the simulation-based approach that was taken during their math specialization course helped them understand the meaning of these ratios and see how they were connected and depended on angle measures. It was also through these simulations that they were, for the first time, able to see that trigonometric functions are not just related to right triangles, but also have

a deep connection to circles, circular motion, and other forms of cyclical behaviour (which is why they are also known as circular functions). Rabia went so far as to say that she felt as if it was during that B.Ed. course that she studied trigonometry for the first time in any real sense. Not only was she able to see the relationships between angle measures and trigonometric ratios, but she was also able to understand the interdependence of these ratios and their connection to other mathematical relationships such as the Pythagorean Theorem.

Sana reported that her B.Ed. social studies course helped her to understand the concept of a river delta for the first time. She had read about the Indus Delta in her school years, but she had never studied its complex geography and, hence, had always understood it simplistically as a triangular piece of land forming near a river mouth. It was during the B.Ed. course that she was exposed to the complex geography of the Indus Delta through satellite images on Google Earth. Sana also described how her understanding of Karachi as a coastal city developed fully during this course: she had always heard that she lives near the coastal line of the Arabian Sea, but she had never really given it a proper thought. As a resident of the city, she had visited different beaches along this coastline, but she never really connected it to the city's spread along the coastal line. It was only after she was shown extensive maps and images of the city using Google Earth that she was able to develop a comprehensive understanding of the geographical features of Karachi and its location along the Arabian Sea coastline. Another example of how the use of technology and digital visualization tools in social studies aids content comprehension was the teaching of mangroves using Google Earth. According to Sana, she was not aware of how Karachi's mangroves surround its coastal line and protect it from natural disasters. It was only after the instructor showed video documentaries on the mangroves of Karachi and connected these documentaries to aerial images from Google Earth that she was able to see how rich this geographical feature is, how much the ecosystem of Karachi depends on the mangroves, how they surround Karachi's coastline to create a protective buffer between the sea and the city, and how its deforestation can affect the life of Karachi's residents.

Contextual Relevance and Real-World Applications

Another theme that emerged from interviews with student-teachers was the importance of relatability and applicability of the concepts being taught in a classroom. From interviews with mathematics student-teachers, it emerged that none of them had any clear sense of the real-world applications of trigonometry and that the B.Ed. math specialization course helped them see these connections for the first time. For instance, one of the applications of trigonometry that connected directly to the simulations that were shown to the student-teachers was the relationship of trigonometric functions to circular and oscillatory motion, such as the motion of a pendulum or a spring-mass system. They reported that they had never understood how trigonometry could help explain such physical phenomena.

Respondents from the social studies course reported that their instructor made effective use of technology to not only showcase and compare physical features of different geographical areas and cities, but also connect them to human geographical features such as clothing, food, art, architecture, household technology, and transportation. Students and teachers reported that the instructor was able to help them see how physical features of a particular area affect its human features. For instance, Bakhtawar reported that she had never thought about why people in Karachi preferred building their houses with windows facing towards the west. During her in-class explorations using Google Earth, she found that it is quite the opposite in Lahore where people prefer to construct their houses facing southwards. This was later connected to factors such as the direction of the sea breeze and the trajectory of the sun during summers and winters. Similarly, differences in clothing preferences were related to geography. Google Earth and similar technological tools remained at the centre of all classroom explorations. The instructor made a point to give urban student-teachers a vicarious experience of the life of mountain and desert dwellers through virtual field trips. These indirect experiences served as an authentic starting point for the exploration of all related concepts of physical and human geography.

Motivation to Learn

The use of simulations and virtual experiences seems to connect to psychological factors that can impede or facilitate learning. Rabia reports that during her school years, because she did not understand trigonometry on a fundamental level, she used to just skip trigonometry questions in all end-of-term examinations, knowing that she would still pass comfortably. She would only attempt questions of trigonometry that were within her comfort zone of procedural memory: if a question required a straightforward application of memorized formulas that she remembered, she would attempt it, but any question that required slightly deeper reasoning would go unattempt. The abstract treatment of trigonometry in her high-school mathematics classrooms had a severely negative impact on her motivation to learn more about this topic or to approach it with any genuine interest. She went on to compare this with her experience of learning trigonometry during her B.Ed. math specialization course, describing how GeoGebra simulations ignited a newfound interest in the subject, so much so that she wanted to go a step further and learn the software itself in which these simulations were created.

Bakhtawar, from the social studies strand, reported that growing up, she never really liked the subject of geography and she found discussions on geography abstruse and uninteresting. She ended up believing that subjects such as geography and social studies consisted of facts about physical features and locations, that just had to be rote memorized. The learning of social studies, geography, history, and other subjects remained an uninspiring experience for her throughout her school years. This would change during her B.Ed. social studies course, which, according to her, radically transformed the way she perceived this subject. She was fascinated by the virtual field trip experiences created by her instructor and found Google Earth explorations equally intriguing. Digital visual experiences changed the way she perceived the subject of social studies: it was no longer a boring collection of facts that had to be memorized; rather, it was a fascinating world of meaningful ideas that were deeply connected to the way we live and prosper.

Discussion

The results of this study align with findings from wider academic literature on the perceived and real impact of technology in enhancing the subject matter competence of pre-service teachers. As already stated, several research studies from around the world attest to the potential of technology to bridge gaps in content comprehension of pre-service teachers in different subject areas, thereby preparing them to be effective teachers of those subjects (Misfeldt & Zacho, 2016; Sherman-Morris et al., 2009; Weinburgh et al., 1997; Wright & Wilson, 2009). The responses of student-teachers participating in this study also point towards the positive impact of technology in building prospective teachers' command over concepts and skills that they will teach in their future teaching practice. All interviewed student-teachers acknowledged that the use of simulations and other digital experiences helped clarify complex ideas, made them more interested in learning difficult and complex concepts, and helped build a deeper appreciation for the real-world applicability of mathematics and social studies. They highlighted the power of technological simulations and experiences in helping them visualize ideas and relationships that were difficult to do by simply listening to verbal explanations or studying static models. The findings of the study, thus add to existing evidence regarding the potential of technology in bridging teachers' content comprehension gaps and preparing them to teach school-level subjects in a meaningful and engaging way.

CONCLUSION

The findings of the study revealed that the use of technology-based simulations and other immersive experiences had a positive impact on content comprehension. Student-teachers reported increased engagement, improved understanding of challenging concepts, and a greater ability to apply their knowledge in practical scenarios. They reported that their ability to visualize complex ideas and relationships, connect different concept areas, and relate academic content to their own lived experiences increased because of their experience with technology-integrated instruction. Lastly, they felt that their

motivation to learn significantly improved after learning content through this approach. This research suggests that the use of technology in teacher education courses can positively impact student-teachers subject-matter knowledge and content comprehension.

Limitations of the Research Study

One major limitation of this research is that it bases study conclusion on student-teacher subjective experience of learning content through technology and not on any objective measurement of how much they learned. This qualitative research can be followed up with a quantitative study that measures improvements in the subject-matter competence of student-teachers. In fact, an impact study can be carried out through which a causal relationship between technology-based pedagogy and increased content comprehension can be established. Another limitation of this research is that it does not bifurcate between primary and middle-school level content when exploring the relationship between technology-based pedagogy and content comprehension. Further studies could explore the relative differences between the impact of technology at different levels of the educational ladder.

Implications for Further Research and Practice

While the focus this research is the relationship between technology-integrated instruction in B.Ed. classrooms and subject-matter competence of student-teachers, it also holds significant implications for enhancing pedagogical practices in the fields of mathematics and social studies. The results of our analyses suggest that incorporating technology tools in teacher education programs can potentially enhance pedagogical practices by providing engaging and interactive learning experiences. By leveraging technology in this manner, teacher education programs in Pakistan can better equip aspiring educators with the necessary skills and knowledge to deliver quality instruction, ultimately benefiting students' learning outcomes in mathematics and social studies. While further research needs to be conducted to understand the relationship between technology-based pedagogy in teacher education colleges and the graduated teachers' teaching capabilities, the responses of the participants of this research suggest technology might help strengthen student-teachers' pedagogical abilities in addition to bolstering their subject-matter knowledge.

The successful application of technology tools and simulations in teacher education programs opens promising opportunities for their direct implementation in K-12 schools as well, particularly in schools equipped with technological resources such as internet access and computer systems. However, this opportunity was, for the most part, missed in the intervention described in this research. In fact, the one area of improvement that all student-teachers participating in this research identified was that, even though they were exposed to the content being taught through technology, they were not taught how to use the same technology to recreate similar learning experiences in their own K-12 classrooms. While this was not the objective of the intervention described in this research, practitioners and researchers can design and evaluate interventions that cater to this additional objective.

Competing Interest

The authors declare no conflict of interest.

Authors' Biography

[1] **Muhammad Umair Khan** is a Lecturer at the Government Elementary College of Education, Hussainabad in Karachi – Pakistan. He completed his Masters in International Education Policy from Harvard University in Cambridge – USA.

[2] **Zenab Moiz** is is a Lecturer at the Government Elementary College of Education, Hussainabad in Karachi – Pakistan. She completed her Masters in Education from the University of Karachi in Karachi – Pakistan.

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