Proceedings of the 3rd Croatian Conference on Earthquake Engineering - 3CroCEE
19–22 March 2025, Split, Croatia

BUILDING RESILIENT COMMUNITIES: ADVANCING STEM EDUCATION AND EARTHQUAKE ENGINEERING RESEARCH

Roberta Apostolska [(1)], Vlatko Sheshov [(2)], Marija Vitanova [(2)], Goran Jekic [(2)], Elena Delova [(2)], Ana Nanevska [(2)], Filip Manojlovski [(2)], Dejan Ivanovski [(2)]

[(1)] *Professor, Ss. Cyril and Methodious University in Skopje, Republic of North Macedonia, Institute of Earthquake Engineering and Engineering Seismology, Skopje, beti@iziis.ukim.edu.mk*
[(2)] *Professor, Ss. Cyril and Methodious University in Skopje, Republic of North Macedonia, Institute of Earthquake Engineering and Engineering Seismology, Skopje, vlatko@iziis.ukim.edu.mk*
[(3)] *Associate Professor, Ss. Cyril and Methodious University in Skopje, Republic of North Macedonia, Institute of Earthquake Engineering and Engineering Seismology, Skopje, marijaj@iziis.ukim.edu.mk*
[(4)] *Associate Professor, Ss. Cyril and Methodious University in Skopje, Republic of North Macedonia, Institute of Earthquake Engineering and Engineering Seismology, Skopje, jekic@iziis.ukim.edu.mk*
[(5)] *Research Assistant, Ss. Cyril and Methodious University in Skopje, Republic of North Macedonia, Institute of Earthquake Engineering and Engineering Seismology, Skopje, delova@iziis.ukim.edu.mk*
[(6)] *Research Assistant, Ss. Cyril and Methodious University in Skopje, Republic of North Macedonia, Institute of Earthquake Engineering and Engineering Seismology, Skopje, nanevska@iziis.ukim.edu.mk*
[(7)] *Research Assistant, Ss. Cyril and Methodious University in Skopje, Republic of North Macedonia, Institute of Earthquake Engineering and Engineering Seismology, Skopje, filipmanojlovski@iziis.ukim.edu.mk*
[(8)] *Research Assistant, Ss. Cyril and Methodious University in Skopje, Republic of North Macedonia, Institute of Earthquake Engineering and Engineering Seismology, Skopje, ivanovski@iziis.ukim.edu.mk*

Abstract

QuakeSafe is a transformative initiative, supported by UNESCO and funded by Huawei, aimed at deepening students' understanding of earthquake engineering and its implications for safety and sustainability through an innovative educational model. Implemented by the Ss. Cyril and Methodius University in Skopje, Institute of Earthquake Engineering and Engineering Seismology (IZIIS), this project utilizes specialized expertise to create engaging and impactful learning experiences. In response to the urgent need for proactive strategies in seismically active regions, QuakeSafe actively engages high school students through a blend of interactive workshops, hands-on experiments and immersive virtual reality (VR) simulations. These activities, conducted as pilot case studies in six selected schools, are structured within an inquiry-based, problem-solving learning environment that introduces the principles of seismic science and engineering. The use of digital tools and VR experiences provides students with practical understanding into the complexities of earthquake phenomena, aiming to develop critical thinking and problem-solving skills grounded in scientific knowledge.

This paper presents the methodology and outcomes of the QuakeSafe project, emphasizing its effectiveness in enhancing students' understanding of seismic risks while fostering interest in STEM disciplines. Additionally, it discusses the strategic collaborations with educational institutions and local authorities that have supported the project’s successful implementation. The study provides an analysis of pre- and post-assessment surveys measuring the project's influence on students’ knowledge, attitudes, and perceptions regarding earthquake safety and STEM engagement. By integrating digital content into a broader STEM educational knowledge hub, QuakeSafe aspires to create a replicable model for other institutions to strengthen disaster preparedness education. The success of the project is reinforced by partnerships and external support, highlighting the significant impact of collaborative efforts in building safer and more resilient communities.

Keywords: STEM, earthquake engineering, VR, hand-on experiments, QuakeSafe, critical skills, resilient communities.

1. Introduction

Through their collaborative project, UNESCO and Huawei Technologies have joined forces to foster the rethinking and revitalisation of the STEM learning model for the next generations, to confront the most pressing societal needs and global challenges. The project, which aims to advance STEM education, contributes to achieving the 2030 Agenda and the Sustainable Development Goals, notably

SDG 4 – Quality education, SDG 5 – Gender equality, and SDG 9 - Industry, innovation and infrastructure, [1].

Among the five selected projects is the 'Advancing Innovative STEM Education and Research in Earthquake Engineering towards a Sustainable Environment: QUAKESAFE' project, led by Ss. Cyril and Methodius University in Skopje, Institute of Earthquake Engineering and Engineering Seismology (IZIIS). This project focuses on advancing earthquake engineering education and its role in promoting sustainable environmental practices [2], (Fig. 1).

The QuakeSafe project has four main objectives, (Fig. 1):

Figure 1. QuakeSafe project objectives and banner

Within the overall framework of the project, IZIIS conducted the following activities:

1. Develop curriculum and educational materials, including VR stimulation and online applications.
2. Plan and conduct pilot sessions of STEM workshops and hands-on experiments.
3. Evaluate the impact of QUAKESAFE educational activities based on pre-and post-assessment surveys.
4. Scale up STEM educational activities to reach more educational schools and integrate results into STEM educational knowledge hub and regional inventory.

The scientific and educational methodology employed in the QuakeSafe project combines established practices from both STEM education and earthquake engineering. Its goal is to equip students with engineering knowledge and skills and to cultivate proactive mindsets, enabling them to become active contributors to the creation of safe, sustainable, and resilient communities. The methodology is in line with SDG 4, SDG 9, SDG 11 [3] and Guidelines on sustainability science in research and education [4].

Through strategic partnerships with educational institutions and local authorities, the designed innovative educational and research activities are implemented in six selected high/elementary schools in three different cities (Fig.2).

Elementary schools:

Gjorgjija Pulevski, Skope, ООУ ЃОРЃИЈА ПУЛЕВСКИ (ougpulevski-aerodrom.edu.mk)

Krste Misirkov, Gevgelija - Крсте Мисирков (krstemisirkovgvg.edu.mk)

High schools:

Rade Jovcevski Korcagin, Skopje, СУГС Раде Јовчевски - Корчагин - РЈК (rjk.edu.mk)

Vlado Tasevski, Skopje, СУГС „Владо Тасевски“ - Скопје (sugsvladotasevski.edu.mk)

Josif Josivovski, Gevgelija, СОУ „Јосиф Јосифовски“ – Гевгелија (josifjosifovski.edu.mk)

Josip Broz Tito, СОУ „Јосип Броз-Тито“ – Битола (gimnazija-jbt-bitola.edu.mk)

Figure 2. QuakeSafe project – pilot case studies

2. Educational programme

The educational programme was designed to engage participants in an immersive learning experience about structural engineering and earthquake safety. This chapter outlines the programme's three main components: Interactive Presentation, Activities, and Evaluation, (Fig. 3). Each component is tailored to foster understanding, encourage collaboration, and evaluate the learning outcomes effectively.

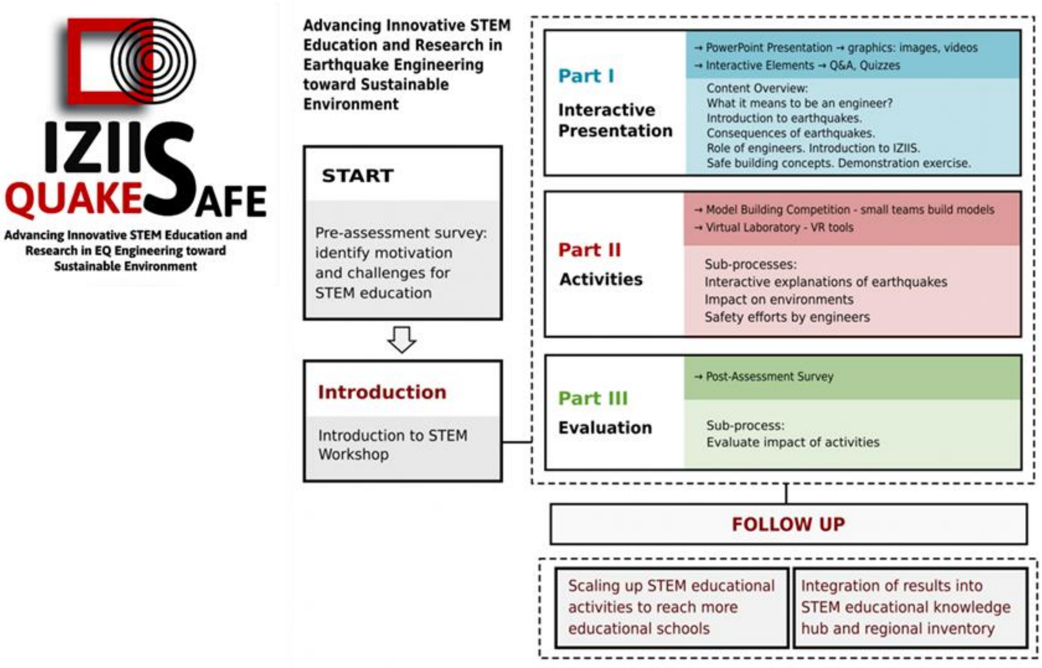

Figure 3. QuakeSafe project in a nutshell

The **Part I** began with an Interactive Presentation, which provides foundational knowledge and sets the stage for deeper engagement. The presentation is delivered using a PowerPoint slideshow enriched with graphic images, videos, and interactive elements like Q&A quizzes to actively involve participants. The content of the presentation covered six key topics:

I) introduction to the role and responsibilities of structural engineers, emphasizing their importance in creating safe and sustainable structures;

II) a concise explanation of earthquakes, their causes, and the forces they exert on buildings to help participants in understanding the core challenge engineers face in earthquake-prone areas;

III) consequences of earthquakes using real-world examples and visual data, highlighting the devastating effects of earthquakes on structures, communities, and economies;

IV) underscoring the proactive role engineers play in mitigating earthquake impacts, including innovative design and material usage;

V) introduction to IZIIS where the participants were acquainted with the pioneering work of IZIIS in advancing earthquake-resistant engineering solutions and fostering international collaboration and finally

VI) introduction to safe building concepts in which practical principles of safe building design were introduced, showcasing best practices and modern techniques that minimize risks during seismic events.

The interactive elements, such as quizzes and question-answer sessions, enhanced participant engagement, ensuring that the presentation is not just informative but also memorable.

The **Part II** consisted of activities that were meant to translate theoretical knowledge into practical experience. It comprised two key sub-activities designed to challenge participants' creativity and critical thinking: experiencing small laboratory model building challenges and virtual laboratory applying VR tools. The participants were grouped into small teams to design and build structural models. This activity encourages teamwork, innovation, and hands-on application of safe building principles. Each team uses materials to simulate real-world constraints and aims to construct models capable of withstanding simulated seismic forces. Through VR tools, participants explored advanced simulations and scenarios. Details are given in the Chapter 3.

The **Part III**, consisted of evaluation of the overall process and the gained knowledge and interest of the young students in the topic that they participated in. The final component of the programme was designed to assess the effectiveness of the activities and measure participant understanding. Evaluation methods include: (I) team model assessment (the structural models created during the competition were tested for their ability to withstand simulated seismic forces; (II) participant feedback (surveys and questionnaires collected insights about the learning experience, including the interactive presentation, activities, and overall organization of the programme); (III) knowledge testing through a brief quiz on the key concepts of the programme topics, ensuring the educational objectives have been achieved. Details are given in the Chapter 4.

By integrating interactive presentations, hands-on activities, and thorough evaluations, this educational programme was focused not only to inform, but also to inspire young students to appreciate and potentially find themselves in the critical role of structural and earthquake engineers in building a safer, more resilient world.

3. Advance educational resources

Incorporating innovative approaches to STEM education is essential for enhancing student engagement and understanding, particularly when addressing complex scientific and engineering concepts. The educational programme integrates advanced resources, blending hands-on activities with cutting-edge technology to provide a comprehensive learning experience. These resources include the Competition for Building Small Models and the Virtual Laboratory Experience, which combine creativity, critical thinking, and immersive learning to inspire students and foster practical skills. This Chapter highlights these activities, showcasing their role in connecting theoretical knowledge with real-world problem-solving in the fields of earthquake engineering and building resilience.

The small-scale shake table tests provided students with an engaging opportunity to step into the roles of engineers, builders, and researchers. Participants worked in small teams to design and construct models, which they then tested. A total of three models were built and tested simultaneously on a small shake table. Students used Mola Structural Kit 1 models (Fig. 4), which consisted of identical sets of elements that were assembled using magnetic connections. To facilitate the testing, a specially designed container (Fig. 4) was constructed to house all three models during dynamic loading. The excitation function applied was a simple sinusoidal signal with varying amplitude and frequency, simulating a realistic earthquake scenario. The APS 400 shaker (Fig. 4) was employed as a mobile shake table due to its lightweight construction and excellent performance.

The tests involved gradually increasing the shaking intensity. One model served as a benchmark, representing a well-designed and well-constructed building, while the other two models had bracing elements intentionally removed to simulate flaws in construction or design. As the shaking intensity increased, students observed the effects of earthquake forces and the comparative responses of well-built versus flawed structures. This hands-on activity fostered innovation and practical application of engineering principles, while highlighting the importance of teamwork, communication, and social skills. By blending creativity with technical challenges, the exercise inspired students to think like engineers and approach real-world problem-solving in a fun and interactive way.

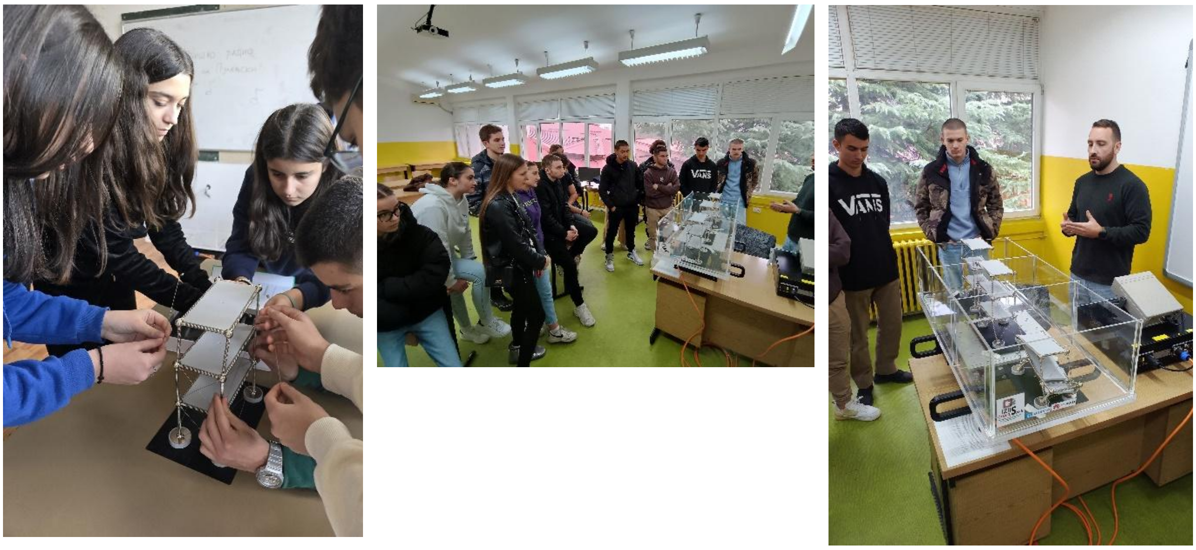

Figure 4. Building and testing engineering models

The Virtual Laboratory Experience offered an immersive interactive journey where students used VR tools to explore the science of earthquakes and the critical role engineers play in ensuring structural safety. The tour utilized three sets of Meta Quest 2 headsets, allowing for efficient rotation and engagement (Fig. 5). With each session lasting 4 minutes, plus an additional minute for setup per student, up to 15 students could participate within a half-hour. This setup was designed to ensure all students had the opportunity to experience the VR tour. The interactive simulations are in eight different scenes, with the journey starting deep within the Earth’s interior exploring the layers that drive tectonic plate movement and cause earthquakes. This captivating introduction to geoscience features vivid visualizations and interactive explanations, helping students grasp complex concepts such as fault lines, seismic energy, seismic waves, and the relationship between plate movements and earthquake phenomena. The interactive journey continued in a simulated room setting where the students could visually experience a real earthquake and its impact on objects within the environment. The students also learned how scientists and engineers measure seismic activity and experimentally analyze the structural response. The VR tour concluded at the IZIIS laboratory, where the students could observe videos and images of scaled-down structural models tested on IZIIS' seismic platform. The structured timing and rotational use of headsets ensured accessibility and inclusivity for all participants, maximizing engagement and educational impact.

Figure 5. The virtual world of the earthquakes

By blending cutting-edge technology with interactive learning the VR Laboratory Experience, were set to not only deepen students' understanding of earthquake science, but also inspire an appreciation for the innovative efforts of engineers in creating a safer built environment.

4. Results from pre- and post- assessment surveys and quizzes

4.1. Survey outcomes

A series of pre-assessment and post-assessment surveys were conducted among students from elementary and high schools participating in the QuakeSafe project. A total of 144 responses were collected to evaluate the effectiveness of the workshops and their impact on students' knowledge and perceptions of STEM disciplines and earthquake engineering[1]. The QuakeSafe project focuses on fostering an innovative STEM education environment, emphasizing earthquake engineering and sustainable practices, particularly for regions prone to seismic activity.

Before the workshops, only 12% of students reported having a clear understanding of STEM disciplines, while 35% indicated some familiarity but lacked detailed knowledge. Another 35% had minimal knowledge, and 18% were entirely unfamiliar with the concept. After the workshops, 78% of students reported a clear understanding of STEM disciplines, 17% indicated some familiarity but not in detail, and only 5% had minimal knowledge. Notably, no students reported being entirely unfamiliar after the workshops (Fig 6).

Regarding their knowledge of earthquakes, 16% of students stated before the workshops that they had a strong understanding of topics such as earthquake causes and measurement scales. Additionally, 48% reported sufficient knowledge, 33% indicated moderate knowledge, and 3% reported insufficient knowledge. Post-workshop results showed a significant improvement, with 69% of students reporting a strong understanding, 27% sufficient knowledge, 5 students indicating moderate knowledge, and only 1 student reporting insufficient knowledge, (Fig. 7).

[1] The response is evaluated based on the five workshops conducted.

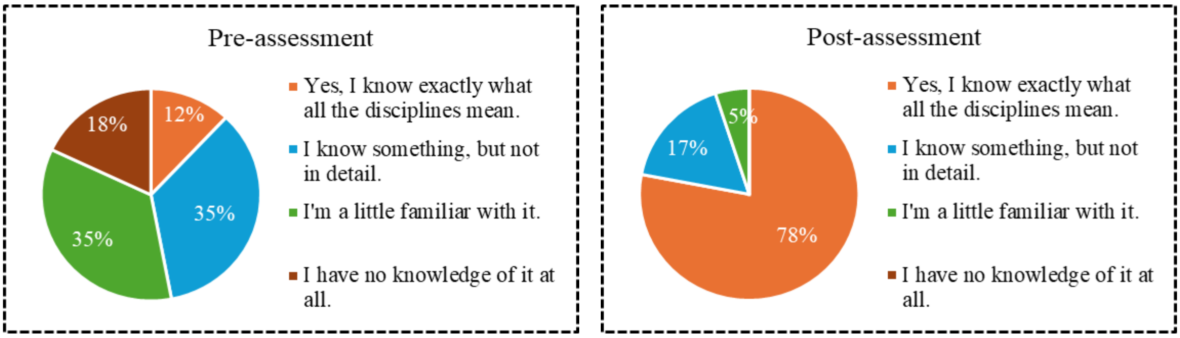

Figure 6. Results from the question: "Are you familiar with what the disciplines in STEM (Science, Technology, Engineering, and Mathematics) mean?"

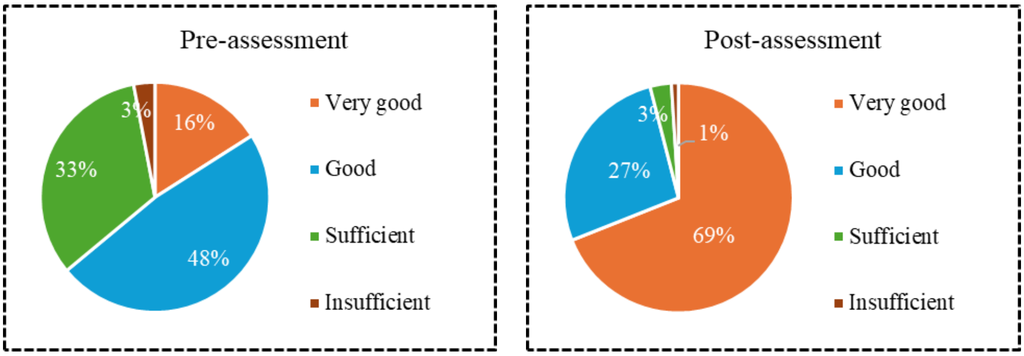

Figure 7. Results from the question: " How extensive is your knowledge of earthquakes (what an earthquake is, where and how it occurs, how it is measured, which scale is used...)?"

Figure 8 shows students' response to the question posed about the role of engineers in ensuring safety against earthquakes. 75% of students reported limited knowledge before the workshops, 8% stated they had extensive knowledge, and 17% indicated no knowledge at all. After the workshops, 74% of students reported extensive knowledge, 25% indicated limited knowledge, and only 1 student reported no knowledge.

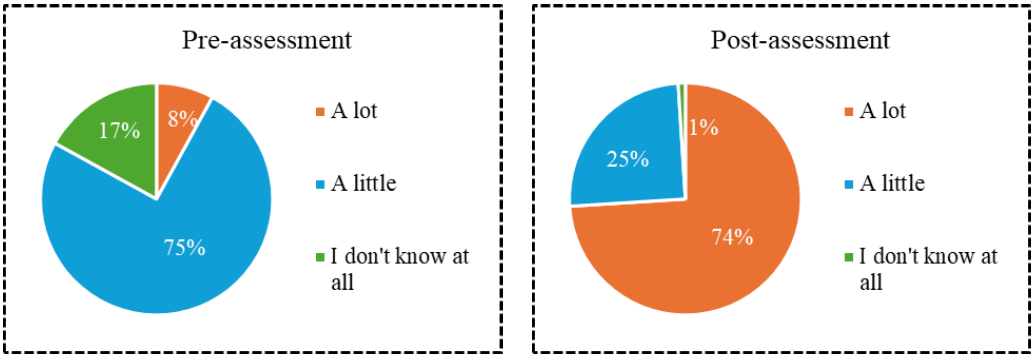

Figure 8. Results from the question: "How much do you know about the role of engineers in protecting people and structures from earthquakes?"

In terms of whether STEM disciplines can help in building safe structures, 88% of students believed they could before the workshops, while 10% were unsure and 2% believed they could not. Post-workshop, 97% of students believed STEM disciplines could contribute to building safe structures, 2% remained unsure, and only 1 student believed they could not (Fig. 9).

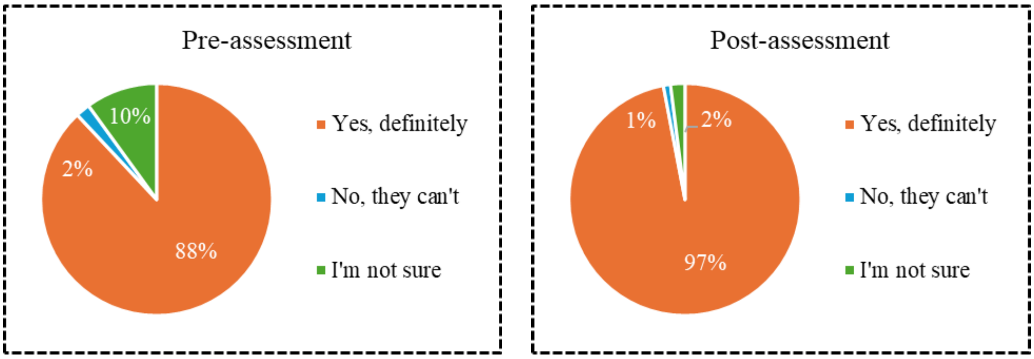

Figure 9. Results from the question: " Do you think that STEM disciplines can help in building safe structures?"

The interactive presentations were also well received (Fig. 10) with 93% of students finding them highly engaging and useful for enriching their knowledge, while 7% found them somewhat useful. Similarly, the VR simulations were considered very engaging and effective by 93% of students for understanding engineering problems. Another 6% found them somewhat effective, and only 1 student was unsure of their usefulness.

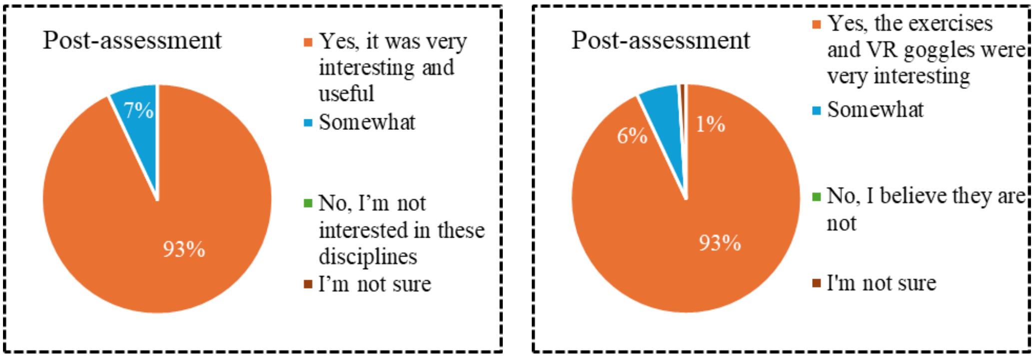

Figure 10. Results from the statements: "The interactive presentation was helpful in enriching my knowledge about earthquakes and how to build safe structures." And "The demonstration exercises with the models and VR goggles are an excellent method for interactive learning and understanding engineering problems"

All these results show that the QuakeSafe project demonstrated a significant improvement in students' understanding of STEM disciplines, earthquake engineering, and the role of engineers in creating safe and sustainable environments. Through the project's innovative approach, students gained deeper insights into complex scientific concepts and their real-world applications. The integration of interactive presentations, model building competitions, and VR simulations proved highly effective in fostering engagement and enhancing learning outcomes. By providing students with immersive experiences and opportunities for creativity, the project successfully bridged the gap between theory and practical application, allowing them to better understand the importance of engineering solutions for natural disaster preparedness.

Moreover, the use of technology-enhanced learning tools encouraged critical thinking, problem-solving, and collaboration among students, preparing them for future challenges in STEM fields. These results underscore the importance of incorporating such innovative and interactive methods into STEM education, particularly for younger generations who will be the leaders in the future of sustainable infrastructure and disaster resilience.

4.2. Quiz outcomes

The online quiz (Fig. 11), an integral part of the QuakeSafe Project workshop, proved to be a highly engaging and successful initiative, effectively reinforcing the knowledge gained during the interactive presentation. With 12 precise designed questions, the quiz challenged students to apply concepts they had learned about earthquake engineering, such as the causes and effects of seismic activity, the role of structural engineers, and principles of earthquake-resistant design. The competitive nature of the quiz added an exciting dimension, making the learning process both stimulating and enjoyable for students. This combination of education and entertainment kept the young people highly motivated, ensuring that the knowledge gained during the presentation was retained and understood at a deeper level.

The results demonstrated the workshop's impact on enhancing student understanding. At the high school “Vlado Tasevski” in Skopje, 82% of participants answered correctly, while 81% of students from “Rade Jovchevski Korchagin” in Skopje also achieved impressive accuracy. Similarly, students from the primary school “Gjorgija Pulevski” in Skopje attained a 75% success rate. Schools in Gevgelija also showcased remarkable results, with “Krste Misirkov” achieving 69% and “Josif Josifovski” achieving outstanding 82% accuracy rates. These statistics highlight the students' ability to understand and apply the material, underscoring the effectiveness of the workshop’s pedagogical approach. Moreover, the results provided a valuable metric for understanding the areas where students excelled and those requiring further elaboration for future educational applications.

Figure 11. Quiz time

These results clearly demonstrated the success of the initial segment of the workshop, as the interactive presentation received exceptionally positive feedback from the participants. A particularly notable feature was the quiz’s competitive character, which brought an added dimension of fun and engagement for the students. This competitive element transformed the quiz into a dynamic and stimulating activity, encouraging students to participate enthusiastically while simultaneously reinforcing the material presented earlier. By fostering a lively and interactive environment, the quiz ensured that learning extended beyond passive listening, actively involving students in applying their knowledge. It became not only an educational tool but also a source of enjoyment and motivation, further deepening their interest in and commitment to understanding earthquake engineering and safety principles. This blend of competition and education proved to be an effective strategy for enhancing engagement and making the learning process both memorable and impactful.

Beyond its educational value, the quiz contributed significantly to raising awareness about earthquake safety and the role of engineering in mitigating seismic risks. Many participants expressed increased confidence in their understanding of the subject, noting that the combination of visuals, interactive discussions, and the quiz solidified their catch of complex concepts. The competitive spirit of the quiz fostered collaboration and healthy rivalry among the students, further enhancing their learning experience. Teachers noted the enthusiasm of the participants, who actively engaged with the questions and demonstrated curiosity about broader applications of the principles discussed.

5. Conclusions

QuakeSafe project is designed to provide students with innovative STEM education and research activities focused on earthquake engineering toward safe and sustainable environment. In response to the pressing need for proactive measures in earthquake-prone regions (including most of South-East

Europe and Mediterranean), this project seeks to equip students with essential knowledge and skills to enhance their understanding of the earthquakes and their impact on the global environment. Through a series of dynamic and engaging educational and research activities, including interactive workshops, hands-on experiments, online applications, and virtual reality (VR) simulations, in the inquiry-based and problem-solving learning environment, students learn about the basic principles of seismic science and engineering and developed their critical thinking based on scientific facts.

Acknowledgements

This project is funded within the framework of the UNESCO and Huawei collaboration, "Revitalizing STEM education to equip next generations with STEM competency".

References

[1] https://www.unesco.org/en/articles/revitalizing-stem-education-europe (accessed 15.12.2024)

[2] https://www.iziis.ukim.edu.mk/en/quake-safe/ (accessed 15.12.2024)

[3] https://www.undp.org/sustainable-development-goals (accessed 15.12.2024)

[4] https://unesdoc.unesco.org/ark:/48223/pf0000260600 (accessed 15.12.2024)