Unlocking Potential: Advancing STEM Learning with Infento, 3D Printing, and Extended Reality

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Abstract. This paper explores into the transformative potential of integrating the Infento Kit, 3D printing technology, and Extended Reality (ER) into STEM education for primary and secondary school students. STEM (Science, Technology, Engineering, and Mathematics) education stands as a valid option in preparing students for the complexities of the future, endowing them with critical thinking, problem-solving, and collaboration skills essential for success. The Infento Kit presents a dynamic, interdisciplinary approach to learning, enabling students to construct an array of structures and mechanisms through hands-on exploration. Augmented Reality further elevates this educational experience by seamlessly integrating immersive digital overlays, thereby enriching the learning environment and fostering heightened engagement. Moreover, the integration of 3D printing technology augments the hands-on learning experience, opening up new avenues for innovation and creativity. By conducting a thorough examination of pedagogical strategies, practical implementation methods, and compelling case studies, this paper underscores the immense potential of this integrated approach to revolutionize STEM education. Ultimately, by empowering students with these innovative tools and methodologies, we aim to cultivate a generation of lifelong learners and innovators poised to navigate and shape the future with confidence and competence.

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1 INTRODUCTION

STEM education is increasingly recognized as essential for preparing students to thrive in a rapidly evolving technological landscape [10], [8]. Traditional approaches to teaching STEM subjects often lack engagement and fail to foster genuine curiosity and passion for learning [7]. However, emerging technologies such as the Infento Kit [3], 3D printing, and Augmented Reality offer exciting opportunities to revolutionize STEM education, providing immersive, hands-on experiences that ignite students' imagination and creativity. This paper explores the synergistic relationship between these innovative tools and their potential to transform STEM learning in primary and secondary schools.

In recent years, there has been a growing emphasis on integrating experiential learning and project-based activities into STEM curricula. The Infento Kit, with its modular construction system, empowers students to design, build, and test their creations, fostering a hands-on approach to learning engineering principles and design thinking. By engaging in real-world problem-solving tasks, students not only gain practical skills but also develop critical thinking and collaboration skills essential for success in STEM fields.

Furthermore, 3D printing technology enables students to bring their ideas to life by designing and prototyping objects with precision and efficiency. This hands-on approach to manufacturing allows students to explore concepts such as geometry, material science, and mechanical engineering in a tangible and accessible way. Moreover, 3D printing encourages experimentation and iteration, empowering students to refine their designs and learn from failure a crucial aspect of the engineering design process.

Augmented Reality (AR) adds another dimension to STEM education by overlaying digital content onto the physical world, creating interactive and immersive learning experiences. AR applications allow students to visualize abstract concepts, simulate scientific phenomena, and explore virtual environments, enhancing their understanding and retention of complex subjects. By integrating AR into STEM curricula, educators can captivate students' interest and inspire a deeper appreciation for the interconnectedness of science, technology, engineering, and mathematics.

2 THE INFENTO KIT

The Infento Kit stands as a versatile educational marvel, offering students a gateway to constructing an extensive array of riding vehicles, ranging from simple modes of transportation to intricate mechanisms. From walkers to scooters, tricycles to bicycles, go-karts to sledges, and beyond, this kit transcends mere assembly to ignite the spark of innovation in young minds. Its modular design and comprehensive instructional materials serve as a scaffold for exploration, allowing students to delve into the fundamental principles of physics, engineering, and design with hands-on fervor.

By immersing themselves in the process of constructing and experimenting with their creations, students not only cultivate problem-solving skills but also hone their spatial reasoning abilities and forge a deeper understanding of STEM concepts. Augmented Reality augments this educational journey by providing a dynamic guide to assembly, offering step-by-step instructions and interactive demonstrations that bring learning to life.

The collaborative nature of the Infento Kit fosters teamwork and camaraderie among students as they join forces to brainstorm ideas, tackle challenges, and refine their designs through iterative processes. With an emphasis on creativity and exploration, the Infento Kit nurtures a growth mindset, empowering students to embrace challenges with confidence and take ownership of their learning journey.

Moreover, the origins of the name Infento shed light on its essence, derived from the Latin terms infinitus (infinite) and planto (to make). This embodiment of boundless creation is further exemplified by the main features of the kit, characterized by squared structural profiles. However, in this project, a strategic modification has been made to optimize performance utilizing lightweight aluminum hollow pipes to reduce the overall weight of the vehicle.

Amidst the combinations offered by the Infento kit, one particular variant takes center stage: the Infento Mini-bender as can be seen from Figure 1. This selection represents a fusion of ingenuity and practicality, offering a glimpse into the endless possibilities awaiting exploration within the realm of STEM education.

3 3D PRINTING TECHNOLOGY

In addition to the Infento Kit, 3D printing technology emerges as a pivotal tool, offering students boundless opportunities to unleash their creativity and bring their ideas to fruition. With the power of 3D printing at

Figure 1: Mini-bender, from Infento KIT.

their fingertips, students are empowered to design and fabricate custom parts and components, opening the door to a realm of innovation and hands-on learning [1], [2].

By harnessing the capabilities of 3D printing, students can swiftly prototype their concepts with precision and efficiency, transforming digital designs into tangible prototypes with remarkable speed [6]. This rapid prototyping process not only accelerates the iterative design cycle but also instills in students a sense of agency and ownership over their creations.

Whether crafting bespoke components for their Infento creations or venturing into uncharted territory with entirely new projects, 3D printing technology amplifies the scope of hands-on learning, enabling students to explore, experiment, and innovate like never before.

To manufacture the connection elements essential for their projects, two cutting-edge 3D printers from Sharebot, a renowned industry leader, are enlisted [9]. The Sharebot One (Figure 2), renowned for its reliability and precision, boasts a commendable resolution of up to 0.08 millimeters and a printing area of 150x150x150 mm. This workhorse is capable of printing with PLA (Polylactic acid), a biodegradable material derived from renewable resources, renowned for its mechanical strength and environmental sustainability.

(a) Sharebot One (b) PLA filament

Figure 2: Sharebot one kit

The workflow begins with the design of components in Autodesk Inventor, followed by the generation of .stl files, which are then processed using 'Sharebot Continuum' software to convert them into .gcode. A layer thickness of 0.3 mm is adopted, striking a balance between accuracy and efficiency to yield optimal results in a timely manner.

In tandem, the Sharebot Next Generation steps up to the plate with its resolution of 0.05 millimeters and a spacious printing area of 250x200x200 mm. This versatile machine offers the flexibility to print with both PLA and TPU (Thermoplastic Polyurethane), catering to a diverse range of project requirements and material preferences.

With these state-of-the-art 3D printers at their disposal, students are poised to embark on a journey of discovery and innovation, pushing the boundaries of what is possible and transforming their visions into reality with unparalleled precision and creativity.

4 EXTENDED REALITY

Extended reality (XR) technologies are on the brink of transforming STEM education by offering immersive and interactive learning experiences that transcend traditional classroom boundaries. XR encompasses a spectrum of technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), each presenting unique opportunities to engage students in dynamic ways [11]. Through XR, students can explore abstract concepts, conduct virtual experiments, and interact with three-dimensional models in ways that were previously unimaginable. By harnessing XR in STEM education, educators can create compelling learning environments that cater to diverse learning styles, fostering curiosity, creativity, and critical thinking among students. Moreover, XR enables students to bridge the gap between theory and practice, empowering them to apply theoretical concepts in real-world scenarios and develop practical skills essential for success in STEM fields. As XR continues to evolve, its integration into STEM education holds tremendous promise for inspiring the next generation of innovators and problem solvers, positioned to shape the future of technology and innovation.

4.1 Augmented Reality

Augmented Reality (AR) technology emerges as a game-changer in the realm of education, seamlessly blending digital content with the physical world to create immersive and interactive learning experiences [4], [14]. Through the integration of AR applications, educators wield a powerful tool to transcend traditional teaching methods, offering students unparalleled opportunities to explore abstract concepts and scientific phenomena in a dynamic and engaging manner [5], [12].

Augmented Reality empowers students to visualize complex theories, conduct virtual experiments, and dissect scientific principles with unprecedented clarity and depth. By overlaying digital simulations onto their physical surroundings, AR technology bridges the gap between theory and practice, offering a hands-on approach to learning that resonates with learners of all ages and backgrounds.

To illustrate, we have developed an augmented reality app tailored specifically for use with the HoloLens, a cutting-edge AR device. This app serves as a guide to assembly for the Infento Kit vehicles, offering students real-time feedback and personalized learning experiences tailored to their individual needs and progress. Through interactive visualizations and step-by-step instructions, the AR app empowers students to navigate the intricacies of vehicle assembly with confidence and precision, fostering a deeper understanding of engineering principles and design concepts.

Figure 4 captures the essence of this transformative technology, showcasing students fully immersed in the AR experience as they engage with the app to assemble their Infento Kit vehicles. This immersive learning environment not only promotes active engagement but also cultivates critical thinking, problem-solving skills, and collaboration among students.

In essence, Augmented Reality revolutionizes the educational landscape by offering a gateway to experiential learning that transcends the confines of traditional classrooms. By harnessing the power of AR technology, educators can inspire a new generation of learners to explore, innovate, and discover the wonders of STEM disciplines with boundless curiosity and enthusiasm.

Figure 3: Students while using the AR app.

5 MIXED REALITY

Utilizing mixed reality through the Meta Quest 3 device, students are guided through an immersive experience in assembling an Infento vehicle with intuitive step-by-step instructions. The Meta Quest 3 seamlessly integrates digital overlays into the physical environment, enhancing the assembly process and facilitating a deeper understanding of the vehicle's construction. Students are transported into a virtual workspace where they can interact with virtual components and visualize assembly procedures in real-time. With each step, detailed instructions and visual cues are provided, guiding students through the intricacies of assembling the Infento vehicle with precision and ease. Through this immersive mixed reality experience, students not only develop practical skills in vehicle assembly but also gain a comprehensive understanding of STEM concepts underlying the construction process.

6 INTEGRATION OF TECHNOLOGIES

By combining the hands-on construction capabilities of the Infento Kit with the design adaptability afforded by 3D printing and the immersive overlays of Augmented Reality (AR), educators unlock a realm of transformative learning experiences that seamlessly merge theory with practice. Picture this: students leverage 3D printing software to craft bespoke parts tailored to their creative vision, then bring them to life through fabrication with a 3D printer, seamlessly integrating them into their Infento creations. Augmented Reality steps in to elevate the learning journey, providing invaluable guidance and instructions for assembly, thereby enriching the learning process and fostering deeper comprehension. Through the fusion of these cutting-edge technologies, educators tailor instruction to suit diverse learning styles, offering students a multi-dimensional exploration of STEM concepts that transcends traditional boundaries.

In our pursuit of educational innovation, we have developed the augmented reality app using Unity 3D, a state-of-the-art platform renowned for its ability to seamlessly blend digital elements with the real world, delivering an immersive experience for users [13]. Specifically crafted to meet our unique educational objectives, the app serves as a comprehensive guide through every stage of the vehicle assembly process, offering intuitive and clear instructions tailored to users' needs and skill levels. With Unity 3D's advanced functionalities, we've crafted a dynamic and interactive environment where users can visualize each component with precision, gaining a nuanced understanding of its placement and function. From foundational principles to intricate

Figure 4: Students while using the MR app.

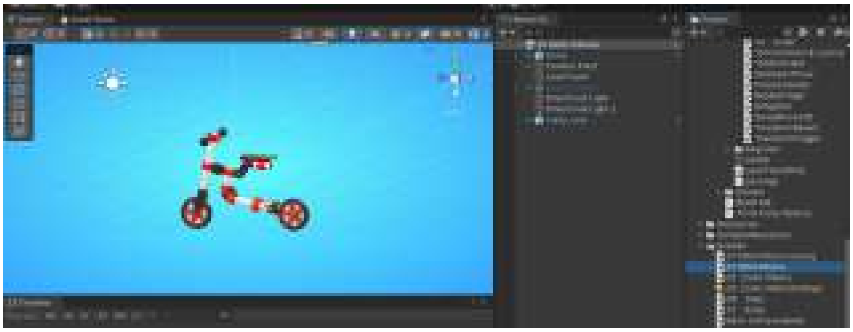


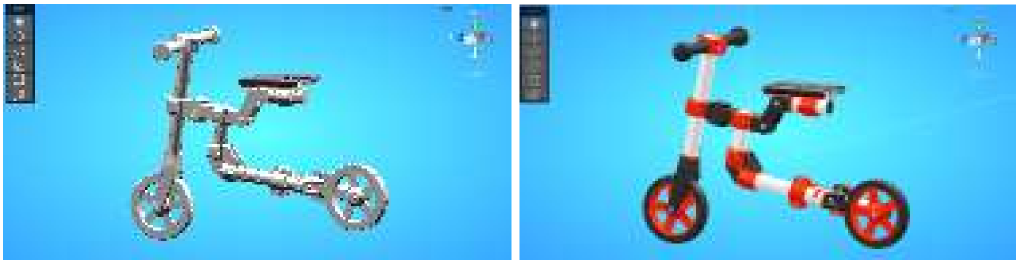
Figure 5: Unity software overview

details, the app ensures a holistic learning experience, making the assembly process accessible and engaging for learners of all backgrounds and proficiencies.

Figure 5 provides an overview of the Unity software, illustrating the sophisticated interface and capabilities that underpin the creation of our augmented reality app. This innovative tool serves as a testament to our commitment to pushing the boundaries of educational technology, empowering educators and learners alike to embark on a journey of discovery and innovation in the realm of STEM education.

Starting from an "Inventor" CAD file, the assembly is first imported in "3DS Max", through which is possible to generate a specific file extension (.fbx) then imported on Unity. Since the .fbx file is generated material-free (6a), it is required to add the rendered material to the model, through assets available in Unity environment, and give it a realistic material appearance (6b).

Some animations were imported from Inventor CAD software, to create a static/dynamic scenario for our model, while for the exploded views the process was directly implemented in Unity. Here below some images of the application scenes are shown:



(a) Uncoloured model (b) Coloured model

Figure 6: Material application

Figure 7: Dolly command scene

Every scene in the "Game mode" has a label that identifies the Infento "Roady" model and a subtitle that provides the indications for that particular slide. A description of the model is given in the opening slides as well. A previous and a next button on each slide guides us through the project. Moreover, an exit button is provided in the upper right corner, allowing to close the application. The project can be seen again from the beginning on the last slide. To ensure a seamless user experience and a clear project, our design consists in simple previous and next buttons.

7 TESTING THE APP

The usability of any newly developed product, system, application, or software should always be evaluated. Understanding the response of users, especially primary and secondary school students who may have varying needs and characteristics, is crucial. It is nearly impossible to gauge the usability of a system or tool without considering the context in which it is used and the corresponding users. In essence, it is impractical to compare and classify the usability of different systems that cater to different contexts or users, as they essentially have nothing in common. Conversely, features, layouts, or procedures that are effective in a specific environment may not always be suitable in a different context. Generally, usability measures can be categorized into effectiveness (the ability to complete tasks using the system and the corresponding output quality), efficiency (the amount of resources used in performing the task), and satisfaction (the users' subjective reaction to using the system).

Primary and secondary school students, including those with neurodevelopmental disorders, may encounter challenges with hand movements, making applications that rely on touch and gesture inputs particularly

Figure 8: Exploded view, frame body

Figure 9: Exploded view, handlebar junction

valuable as they leverage technology to assist these students. However, existing literature suggests that the quality of hand-gesture interactions during cognitive exercises can lead to positive outcomes. Therefore, conducting a usability test is important to understand the students' perceptions of the application. To that end, the Desktop version, Android tablet version, and the Microsoft HoloLens version of the developed application were tested by 21 students from the Tommaso Grossy Secondary School.

8 SYSTEM USABILITY SCALE - SUS

The System Usability Scale (SUS) proposed by John Brooke in 1986 was utilized for this purpose. This tool comprises a 10-item questionnaire with five response options, ranging from 'strongly agree' to 'strongly disagree'. It facilitates the evaluation of a broad array of products and services, including applications. In order to ensure optimal learning outcomes for the students, the application was initially introduced with the assistance of a projector. This guided students in understanding all the crucial aspects of the process. Subsequently, participants had the opportunity to individually interact with both, the HoloLens and Quest3 versions of the application. Some students found it challenging to associate their answers with the traditional scale of the SUS, which employs a 5-point Likert Scale ranging from 'strongly disagree' to 'strongly agree'.

To simplify this, the scale was adjusted to utilize a 5-smiley representation. Moreover, the questionnaire was orally administered by the educators to the students. This approach served a dual purpose; it helped clarify any ambiguous questions and enabled the clear identification of the students' responses on the scale. Spontaneous comments made during and after the interaction with the devices were also taken into consideration to gain a more comprehensive understanding of their experience.

Table 1: SUS questionnaire results for Augmented Reality application (HoloLens). Mean values range from 0 to 4, and negatively worded items have been normalized. The system obtains 85.2 / 100

	Statement	Likert Scale (1:5)	Normal Mean (0:4)	Std. Dev.
1	I think that I would like to use this system frequently	4.45	3.45	0.93
2	I found the system unnecessarily complex	2.00	3.00	1.73
3	I thought the system was easy to use	4.73	3.73	0.65
4	I think that I would need the support of a technical person to be able to use this system	2.00	3.00	1.34
5	I found the various functions in this system were well integrated	4.64	3.64	0.50
6	I thought there was too much inconsistency in this system	1.45	3.55	0.69
7	I would imagine that most people would learn to use this system very quickly	4.64	3.64	0.50
8	I found the system very cumbersome to use	1.91	3.09	1.45
9	I felt very confident using the system	4.73	3.73	0.47
10	I needed to learn a lot of things before I could get going with this system	1.73	3.27	1.10
	Total (Sum*2.5)		**85.20**	**17.8**

Table 2: SUS questionnaire results for the Mixed Reality-based application (Quest3) had mean values ranging from 0 to 4, and negatively worded items were normalized. The system obtained a score of 70 out of 100.

	Statement	Likert Scale (1:5)	Normal Mean (0:4)	Std. Dev.
1	I think that I would like to use this system frequently	4.00	3.00	1.26
2	I found the system unnecessarily complex	2.45	2.55	1.44
3	I thought the system was easy to use	4.09	3.09	0.94
4	I think that I would need the support of a technical person to be able to use this system	3.27	1.73	1.42
5	I found the various functions in this system were well integrated	4.27	3.27	0.90
6	I thought there was too much inconsistency in this system	1.82	3.18	1.08
7	I would imagine that most people would learn to use this system very quickly	4.00	3.00	0.63
8	I found the system very cumbersome to use	2.36	2.64	1.29
9	I felt very confident using the system	3.82	2.82	1.08
10	I needed to learn a lot of things before I could get going with this system	2.27	2.73	0.79
	Total (Sum*2.5)		**70.00**	**17.5**

The feedback from the pilot study indicated a high level of interest and engagement among students. Many were excited about the possibility of seeing and interacting with virtual entities, an activity not commonly encountered in their usual learning environment. The data analysis revealed significant differences in usability among the three configurations tested.

The HoloLens configuration received the highest usability score, considered excellent according to the SUS scale (see Table1). In contrast, the Quest3 configuration, posed challenges for some students.

The HoloLens version scored "almost good" in usability. Students expressed high interest and curiosity towards this version, although some faced difficulties with the limited field of view and the novel interaction gestures. With further training and adjustments to the physical settings, these issues could be mitigated.

Both the Quest3 and HoloLens versions achieved scores above the average in the SUS database. These results indicate that the developed applications meet usability standards and are well-received by the students.

Overall, the study concludes that integrating the Infento Kit, 3D printing, and AR in STEM education is highly effective. The positive responses and usability data suggest that these tools can significantly enhance the learning experience, making STEM education more engaging, accessible, and effective for primary and secondary school students.

9 CONCLUSIONS

The integration of the Infento Kit, 3D printing technology, and Extended Reality through the Meta Quest 3 and Hololens devices has demonstrated significant potential in transforming STEM education for primary and secondary school students. This study underscores the multifaceted benefits of incorporating these innovative tools into educational settings, offering an immersive, hands-on learning experience that fosters curiosity, creativity, and critical thinking.

The pilot study involving the Extended reality apps has highlighted the effectiveness of mixed reality in providing intuitive, step-by-step instructions for assembling Infento vehicles. This approach not only enhances students' practical skills in vehicle assembly but also deepens their understanding of fundamental STEM concepts. The use of AR for real-time feedback and personalized learning experiences has been particularly effective in maintaining student engagement and promoting active learning.

The usability evaluation through the System Usability Scale (SUS) revealed positive feedback from primary and secondary school students, indicating that the combination of digital and physical learning tools is both accessible and enjoyable. Adjustments to the traditional SUS, such as the introduction of a 5-smiley representation and oral administration of the questionnaire, proved beneficial in accurately capturing the students' experiences and responses.

Several key conclusions can be drawn from this study:

Enhanced Learning Outcomes: The combination of the Infento Kit, 3D printing, and AR significantly enhances students' understanding of STEM concepts by providing a practical, hands-on approach to learning. This method bridges the gap between theoretical knowledge and practical application, making abstract concepts more tangible and comprehensible.

Increased Engagement and Motivation: The immersive nature of AR, combined with the creative possibilities offered by 3D printing and the Infento Kit, keeps students engaged and motivated. This increased engagement is crucial for fostering a lifelong interest in STEM fields.

Development of Critical Skills: Students develop essential skills such as problem-solving, spatial reasoning, and collaboration. The collaborative nature of assembling Infento vehicles and the iterative process of 3D printing parts encourage teamwork and critical thinking.

Usability and Accessibility: The mixed reality app developed for the Meta Quest 3 proved to be user-friendly and accessible for primary and secondary school students. The tailored usability scale ensured that students' feedback was accurately captured, highlighting the importance of adapting evaluation tools to suit the target audience.

Educational Equity: By providing a versatile and inclusive learning platform, this approach can cater to a diverse range of learning needs and styles, ensuring that all students have the opportunity to benefit from innovative STEM education tools.

Future Directions: The success of this pilot study paves the way for further research and development. Future studies could explore the long-term impacts of such integrated learning tools on student performance and interest in STEM subjects. Additionally, expanding the use of mixed reality and 3D printing to other areas of the curriculum could further enhance educational outcomes.

In conclusion, the innovative integration of the Infento Kit, 3D printing, and Augmented Reality represents a promising advancement in STEM education. By creating a dynamic and interactive learning environment, educators can better prepare students for the challenges of the future, equipping them with the skills and knowledge necessary to thrive in an increasingly technological world. This study serves as a stepping stone towards a more immersive and engaging educational experience, inspiring the next generation of innovators and problem-solvers.

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