ENHANCING ACCESSIBILITY AND USABILITY IN 3D MODELING EDUCATION FOR NOVICE LEARNERS

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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I. Introduction

Educational technology has changed how children and beginners learn and explore complicated subjects, from programming to physics and 3D modeling. Specifically, platforms like Scratch, Monster Physics, and SpacePlace have made learning technical skills easier by introducing intuitive and visually straightforward environments that help with active learning. Scratch makes programming more accessible by introducing block-based coding to allow children to learn computational thinking without being overwhelmed by complicated syntax and rules found in other programming languages. Another example is Monster Physics, which is a platform that introduces engineering concepts using interactive simulations, and NASA's SpacePlace makes learning astronomy enjoyable by using interactive animations and games. All these platforms show how platforms that are designed with accessibility in mind can foster curiosity, creativity, and problem-solving skills in young and novice learners.

Although programming and STEM topics learning have benefited from these beginner-friendly platforms, 3D modeling and animation tools are mostly inaccessible to novices. A lot of 3D platforms used today feature interfaces that are overloaded with commands and workflows that assume prior experience since they are designed for professionals, such as Blender, Maya, and AutoCAD. Even though some platforms for beginners, such as Tinkercad, have emerged to bridge this gap, they still present challenges in accessibility and integrating in the classroom. Educators report that students often struggle with tasks like changing perspectives and aligning objects because navigation is not intuitive (Bhaduri et al., 2021). These difficulties can decrease students' ability to understand fundamental 3D concepts, which can frustrate them.

Understanding the strengths and limitations of current 3D modeling platforms is crucial for improving their design and educational impact. This paper will explore how interface design, tool availability, and in-classroom use affect the students' learning abilities by examining Tinkercad as a case study.

I will use Actor-Network Theory (ANT) to analyze the relationships between the design of the platform and educators' teaching methods and how they affect students' learning experience. ANT conceptualizes educational technology as part of a socio-technical network, where students, educators, platform designers, and technology itself interact to form learning outcomes (Mlitwa, 2007). ANT eliminates the distinction between human and non-human actors and considers both as integral to the learning process (Law, 1992). This perspective is useful in examining why some educational tools succeed or fail not just based on their design, but based on how they integrate into existing learning environments. These networks need continuous efforts of translation, where all designers, educators, and students must align their goals while also adapting to negotiation within the system (Cressman, 2009). For instance, Tinkercad's interface and pre-designed tools act as durable materials that stabilize the network by supporting usability and learning over time.

However, the effectiveness of these materials depends on relational dynamics, such as educators' teaching methods, students' spatial reasoning skills, and conventional factors that either ease or complicate adoption. Actor-Network Theory provides a framework to analyze how various actors, students, educators, platform designers, and technology itself interact to contribute to the usability and effectiveness of 3D modeling tools. Misalignment of goals of the actors may lead to resistance and challenges in educational adoption. For example, educators often require additional training to effectively implement 3D modeling tools in their curriculum (Deniz & Eryilmaz, 2021). Without instructional strategies and technical support, students may struggle to develop the necessary skills to navigate 3D modeling software effectively.

II. Lessons from Interactive Learning Platforms

Scratch, as an example, showed how interactive learning environments can make complex concepts more accessible to young learners. Scratch introduces block-based coding to simplify coding for children and novice learners. This approach allows learners to focus on problem solving and logic instead of getting overwhelmed with syntax errors and rules. Schools and after-school programs adopted the interactive nature of Scratch to encourage engagement, creativity, and collaboration (Maloney et al., 2008). Additionally, the recent integration of Virtual Reality (VR) and metaverse technologies into STEM education offered new possibilities for interactive learning by putting students in virtual environments where they can visualize and manipulate abstract concepts in ways that traditional teaching methods cannot achieve (Solanes et al., 2023).

HyeJin Lee and Yohan Hwang investigated how hands-on VR content creation and metaverse linking could transform static digital textbooks into immersive learning environments. In the study, pre-service teachers first rebuilt textbook scenes in CoSpace Edu, which is a platform designed to allow students to create 3D virtual worlds and explore them in virtual reality. The teachers constructed a five-building virtual campus populated with 3D avatars and embedded quiz objects that students can access by roaming and clicking within the scene. They also integrated these scenes into individual virtual rooms to customize and present their robotic system designs. The simple hand-tracking gestures and controller inputs to grab and inspect objects in real time improved the mental-rotation challenges found in 2D interfaces. Participants in the study mentioned increased motivation and communication skills and confirmed that this metaverse-linked VR approach made abstract STEM concepts more tangible than conventional digital-textbook methods.

VR environments solve difficulties students might face in traditional learning, like spatial reasoning, by allowing students to interact with their designs in a more natural way, using hand tracking, motion gestures, and real-time manipulation. Also, metaverse-based education makes it more fun and engaging for collaborating, similar to the benefits of Scratch's online community where students can build on each other's projects. However, VR-based STEM education faces challenges related to accessibility and individual user experiences. The financial barrier associated with VR hardware, including headsets, motion tracking devices, and computers can limit access for students in underfunded schools (Solanes et al., 2023). Additionally, not all users experience VR in the same way; some may get nauseous when using VR headsets, which can limit the participation in immersive learning environments (Chang, Kim & Yoo, 2020).

Educators also require training to effectively implement VR-based instruction, as teaching in a virtual space requires new pedagogical strategies and familiarity with immersive technologies (Solanes et al., 2023). Students may struggle to navigate in virtual interfaces without guidance, which can lead to frustration instead of engagement. Institutions must consider strategies such as ergonomic improvements in VR hardware, personalized user settings, and instructor training programs to ensure that VR-based education remains accessible and effective for a diverse range of learners. Another challenge is the presentation skills and cognitive load in virtual environments. In the Valencia study, students initially struggled with navigating the virtual world and asked for additional time to become comfortable with movement and object interaction (Solanes et al., 2023).

Also, these environments require students to develop self-regulation skills since, oftentimes, they must manage their own learning without the instructors or peers. Research conducted by Erhan Delen and Jeffrey Liew has shown that self-regulated learners are more likely to continue learning and have more academic success by monitoring their progress constantly. An approach for self-regulation in online learning is the integration of interactive tools that encourage metacognitive awareness and engagement. For example, features like study logs, journals, and automated progress tracking can help students stay motivated and keep track of their learning habits. Other strategies like goal setting have been found to improve student performance and learning motivation over time. Educators can create environments to support students in developing learning skills in general by including similar tools.

Interactive learning environments provide an advantage over traditional educational methods by giving learners the opportunity to engage with content instead of passively receiving information. However, interactivity only helps learning when it engages deeper cognitive processes, not just by offering obvious actions (Renkl and Atkinson, 2007). Research done by Alexander Renkl and Robert Atkinson on interactivity in computer-based learning environments shows that interaction should direct the users' attention to elementary concepts and principles to make sure they continue to actively learn. This is especially relevant in platforms like Scratch and virtual metaverse environments since interactivity can improve learning. However, this may also lead to distractions if they were not guided. For example, allowing students to control their own learning pace and choose how they interact with content can lead to disorientation or cognitive overload, which is known as "lost in hyperspace" (Renkl and Atkinson, 2007). We can see this in hypermedia learning and complex virtual environments. In these environments, students may focus on surface-level features instead of core learning objectives. Instructional design should prioritize focused processing. This aligns with the approach taken in VR-based STEM education where structured guidance such as self-explanation prompts helps with keeping focus on important objectives and at the same time making use of the immersive nature of virtual environments.

The study on the use of VR and the metaverse in STEM education shows the potential for interactive and immersive learning to keep students engaged. Just as Scratch changed programming education by making learning how to code easier, VR-based environments can help with STEM learning by providing interactive and collaborative experiences. However, the challenges of accessibility, teacher adaptation, and technological requirements must be looked into to make sure that these immersive learning tools can be integrated into mainstream education effectively.

III. Challenges in Existing 3D Modeling Tools for Novice Users

3D modeling platforms, such as AutoCAD, Blender, and FreeCAD have significant challenges for novice users because of their complex interfaces and generalized task design. These platforms often overwhelm beginners with a large number of commands and tools, creating what is referred to as a "spaghetti interface" that makes navigation difficult (Szewczyk & Jakimowicz, 2001). Lacking guided learning pathways makes these tools frustrating for beginners and children. Also, many platforms try to solve the steep learning curve problem through tutorials or instructional videos, but these do not provide hands-on or task-oriented guidance. Beginners following YouTube tutorials, for example, frequently struggle with software version differences, unfamiliar shortcuts, or unclear functions which can lead to confusion and disengagement (Chilana et al., 2018).

A big obstacle for novices is the difficulty to understand spatial tasks, which include perspective changes and mental rotation. These tasks are essential for 3D design. Traditional 3D modeling tools can become even harder for beginners to use without structured built-in or real-time support (Bhaduri et al., 2021). Research conducted by Milada Teplá, Pavel Teplý, and Petr Šmejkal on the influence of 3D models and animations on students suggests that dynamic visualizations, such as 3D models and animations, can improve motivation and learning outcomes particularly in science-related subjects. Implementing 3D visual tools has been shown to improve engagement of students by using active participation and a sense of competence. However, these visual tools depend heavily on instructional design and teacher support. The load of complex software obscures the potential benefits of 3D visualizations for beginners.

These challenges show the need for an alternative approach that combines structured learning, guided tasks, and interactive feedback to help users build confidence and skills without the need to navigate complex interfaces and unnecessary tools. Integrating dynamic visualization improves learning experiences in 3D platforms and makes creative and technical skills more accessible to a wider audience.

IV. Evaluating Tinkercad: Strengths, Limitations, and Classroom Integration

In recent years, 3D modeling platforms like Tinkercad have come out as valuable educational tools that encourage computational thinking for students. Tinkercad is a browser based platform that allows students to create 3D designs that educators can use to teach STEM concepts through hands-on learning. However, Tinkercad faces significant challenges in effective classroom use for novice users who struggle with spatial thinking and the platform's limited design options (Mosiiuk et al., 2023). Tinkercad includes features designed to simplify 3D modeling like pre-made shapes and a basic interface, but these benefits did not translate to classroom success. Educators noted that students often face obstacles with perspective changes, mental rotation, and interface navigation (Bhaduri et al., 2021).

Educators play an important role in Tinkercad's classroom adoption, since their teaching approaches impact its effectiveness. Educators require additional training and support to effectively help students (Deniz & Eryilmaz, 2021). Because of this, there are challenges in integrating Tinkercad in educational environments. Dynamic visualization can improve STEM learning by helping students understand complex concepts through tools like animations and 3D models. This helps cognitive processing by presenting continuous representations and reducing cognitive load (Teplá et al., 2022).

We can better understand the structural barriers that prevent the integration of Tinkercad by looking at its educational adoption as a socio-technical process. Nhlanhla Mlitwa suggests that effective technology use in classrooms requires more than accessible tools, such as interaction between digital platforms and instructional strategies. In the case of Tinkercad, challenges such as educator preparedness, student skills with spatial manipulation, and the software's limited adaptability across age groups show key points of friction within the actor-network. Also, the negotiation between human and non-human actors in digital learning spaces shows broader debates in constructivist vs. instructivist pedagogy, where platforms must balance guided instruction and giving students the space to explore. This shows the need for improvement in educational tools to guarantee that platforms like Tinkercad do not just simplify 3D modeling but also enhance self-regulated learning (SRL) skills to allow students to develop autonomy in technical disciplines.

Additionally, the platform's ability to work across contexts depends on its "mobility," or how its design can make learning easier in diverse classroom environments to guarantee that elements like visual aids and teacher support remain effective regardless of location (Law, 1992). However, conflicting goals among Tinkercad's designers, educators, and students add complexity to these social factors in educational technology. Designers prioritize simplicity to enhance accessibility, but this often limits advanced design capabilities, which may frustrate skilled students and complicate educators' efforts to meet different needs.

Actor-Network Theory helps with understanding these challenges through the concept of translation, which involves aligning the interests and actions of all actors, students, educators, and the platform, into a cohesive network. According to Law (1992), translation is a process that requires continuous negotiation and adaptation to maintain stability and order within the socio-technical network. In Tinkercad's case, failures in translation happen when actors' needs are misaligned: educators often lack the training and resources to effectively teach spatial skills, and the platform's simplicity may not support advanced learners. These gaps create resistance within the network, which destabilizes its structure and limits its effectiveness in classrooms. Translation also involves managing the relational effects of power and resistance. This highlights how the interactions between actors shape the network's strength.

V. Analysis

The fast development of educational technology has transformed the learning process for children and novice learners by making complicated subjects accessible using interactive and intuitive platforms. Despite these advancements, 3D modeling and animation platforms remain inaccessible to beginners due to their overloaded interfaces and steep learning curves. However, a clearer understanding of the challenges and opportunities can be found in 3D modeling education by examining existing 3D modeling tools and the potential of Scratch and VR-based metaverse educational environments.

Platforms such as Blender and AutoCAD were designed primarily for professional use. This leads to platforms that feature interfaces loaded with commands, shortcuts, and menus that assume prior knowledge of 3D space navigation. Beginners struggle with spatial tasks, and this cognitive overload often leads to frustration and disengagement. Additionally, the lack of structured and guided tutorials in these platforms makes it difficult for learners to progress without external support (Chilana et al., 2018). This shows the necessity of having user-friendly instructional design elements similar to those found in beginner-friendly programming platforms like Scratch.

Interactive learning environments have shown promising results in making students more motivated. Studies indicate that 3D models and animations can improve motivation, engagement, and understanding of scientific concepts (Teplá et al., 2022). The use of Dynamic visualization can improve STEM learning by helping students understand complex concepts through tools like animations and 3D models. These tools support cognitive processing by providing continuous representations and reducing cognitive load (Teplá et al., 2022). However, their effectiveness varies based on several contextual factors, such as subject matter, student age, gender, and teacher characteristics. This tells us that a carefully designed instructional strategy is needed when incorporating visual aids in the classroom. Without such tailored approaches, the benefits of dynamic visualization, especially in platforms like Tinkercad, may not be fully realized across different learning environments.

Another critical factor influencing the accessibility of 3D modeling platforms is the "spaghetti interface" effect (Szewczyk & Jakimowicz, 2001). Unlike Scratch, most 3D modeling software lacks a progressive learning structure to help the user gain confidence. Platforms like Tinkercad have attempted to bridge this gap by offering simplified tools for 3D modeling, but they still pose challenges in classroom integration and spatial manipulation tasks (Mosiiuk et al., 2023). Additionally, while Tinkercad provides a more approachable entry point, it lacks advanced features needed for users to transition into more sophisticated modeling software.

Improving the interface design of 3D modeling platforms is crucial, but also an equally important factor is the development of self-regulated learning (SRL) skills that help students navigate complex learning environments. Pedagogical research oftentimes focuses on the presentation of content and the design of tools, but if 3D modeling platforms are complex due to their spatial nature, then an essential skill students must develop is learning how to learn within these environments. Self-regulated learning theory shows that learners must actively set goals, monitor their progress, and adapt their strategies to succeed in challenging educational settings (Pintrich, 1995). Without structured guidance, students may become overwhelmed by the interface and spatial tasks, which could lead to disencouragement to continue learning. Platforms like Scratch succeed because they provide progressive learning structures that allow learners to build confidence gradually. A more effective educational approach would not only simplify interfaces but also incorporate features that promote SRL, such as real-time progress tracking, self-explanation prompts, and guided tutorials. This would help students manage cognitive load and transition more effectively from beginner-friendly tools like Tinkercad to professional platforms like Blender or AutoCAD.

A potential solution to these challenges lies in the combination of structured interactive environments that introduces gradual skill acquisition. This means integrating elements from Scratch and VR-based metaverse platforms to make 3D modeling education become more accessible to a wider audience. Scratch's success demonstrates that interactive, hands-on learning environments can simplify complex technical concepts, while VR environments offer immersive experiences that make students more engaged and understanding. VR-based STEM education has already shown promising results in increasing motivation and retention by allowing students to interact with 3D models in a more intuitive and natural manner (Solanes et al., 2023).

Additionally, Delen and Liew suggest that tools supporting metacognitive awareness and goal-setting improve learning outcomes. Interactive features such as study logs, automated progress tracking, and self-explanation prompts could be integrated into 3D modeling platforms to help students monitor their learning progress and set future goals to accomplish. This approach aligns with instructional design principles that emphasize focused processing and structured guidance to prevent cognitive overload (Renkl & Atkinson, 2007).

In conclusion, while current 3D modeling platforms offer powerful design tools, their complexity limits accessibility for beginners. The integration of structured learning pathways, dynamic visualizations, and interactive elements is a potential solution to make 3D modeling more engaging and intuitive. Future platforms can have a balance between functionality and usability by combining these approaches.

VI. Discussions

The limitations of current 3D modeling platforms show the need for an adaptive and scalable solution that works for both beginners and advanced users. “Beginner-friendly” platforms like Tinkercad works as an entry point for beginners but limits users' ability to develop deeper 3D modeling skills. This creates a gap in the learning process where students struggle to transition from basic modeling to more advanced applications. Future educational tools should integrate features from diverse interactive learning environments. The accessibility of block-based coding in Scratch should be combined with the immersive aspects of virtual reality (VR) metaverse environments to make it both easier and more exciting for beginners to learn difficult concepts.

One potential direction for improving 3D modeling education is adopting a learning system that has multiple tiers similar to Scratch. Scratch has demonstrated how a progressive approach to learning can help users build foundational programming skills before transitioning to more complex coding environments. By applying this model to 3D modeling, beginners could start with simple drag-and-drop interfaces that gradually introduce more sophisticated tools and workflows. This approach would allow learners to gain confidence before engaging with professional software. Also, integrating features such as guided tutorials, real-time feedback, and interactive challenges would provide a more structured learning experience and reduce the frustration encountered by beginners in traditional 3D modeling platforms in the beginning of their learning journey.

VR technology allows users to interact with 3D models in an immersive setting which can make spatial manipulation more intuitive. Instead of relying on keyboard and mouse controls, users can move, rotate, and resize objects using natural hand gestures, improving their ability to visualize and understand 3D space. Additionally, VR platforms can simulate real-world physics and interactions to have students experiment with engineering and architectural concepts more realistically. Combining VR with a structured learning framework, similar to Scratch, could create an accessible 3D modeling environment that adapts to users' skill levels.

Future educational platforms should also prioritize accessibility and inclusivity by addressing the cognitive load associated with learning complex interfaces. Interactive learning environments improve motivation and learning outcomes when they provide clear guidance and structured tasks. A well-designed educational tool should balance the flexibility of professional software with the simplicity of beginner platforms.

The future of 3D modeling education can be manifested in a hybrid approach that merges the strengths of interactive learning environments like Scratch, the spatial intuitiveness of VR metaverse platforms, and the precision of professional-grade modeling tools. Developing an educational system that gradually introduces complexity while maintaining engagement and accessibility will help bridge the current gap in 3D modeling education. A future platform that combines immersive learning and an accessible design for different pathways can have a significant impact on beginners and children by reducing frustration.

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