Innovation Unleashed: A Qualitative Study on Nurturing Creativity through Virtual Reality and Integrated Engineering and Visual Arts Education

Arpita Kurdekar
Integrative Ph.D. Studies (Engineering, Fine Arts, Educational Psychology)
University of Connecticut
Storrs, United States
arpita.kurdekar@uconn.edu

Daniel Burkey
Chemical and Biomolecular Engineering
University of Connecticut
Storrs, United States
daniel.burkey@uconn.edu

Michael F. Young
Educational Psychology
University of Connecticut
Storrs, United States
michael.f.young@uconn.edu

***Abstract*— This research category full paper is about a study that investigates the integration of virtual reality (VR) technology to enhance creativity in a multidisciplinary design context, merging engineering and visual arts education. By immersing students in a VR learning environment, it explores how this approach positively influences creativity, breaking down traditional educational silos and providing a blueprint for incorporating A (art) into STEM (science, technology, engineering, mathematics) education - STEAM. Addressing the global imperative for creativity for problem-solving, the study systematically integrates teaching creativity into education using VR technology and blended curricula. The research investigates factors contributing to embodiment, flow state, and intrinsic motivation experienced during multidisciplinary VR learning. Methodologically, a fully immersive VR environment guided by constructivist learning theory was developed, and 7 undergraduate students from civil, mechanical, and multidisciplinary engineering participated in (virtual) hands-on activities focused on building kinetic sculptures in the developed VR environment using HTC Vive. Based on the participants' experiences, preliminary findings from qualitative interviews indicated positive influences on creative performance, with heightened embodiment, flow, and intrinsic motivation observed among participants. Beneficial outcomes included knowledge gain, enhanced creativity expression through active project-based learning, and recognition of connections between engineering and art fields. Despite challenges like equipment learning curves and stress impact, these findings lay the groundwork for innovative STEAM and VR pedagogy, offering insights for further quantitative/ qualitative studies and advancing creativity development in engineering education.**

***Keywords*— virtual reality; multidisciplinary design; creativity; STEM; flow state; intrinsic motivation**

I. Introduction

In today's rapidly evolving world, driven by globalization and technological advancements, the demand for innovative solutions to unforeseen problems has made creativity an essential 21st-century skill. As such, it is crucial for education systems to prioritize the teaching of creativity, enabling students to develop into versatile professionals capable of addressing future challenges [1], [2].

Despite this necessity, the integration of creativity into educational curricula faces significant challenges, primarily due to educator biases and the resulting lack of environments that foster creativity [3], [4]. Anecdotal evidence provided by Kazerounian and Foley [5] highlights a prevailing mindset in contemporary engineering education that undermines the value of creativity. Common beliefs include the notion that engineering prioritizes accuracy over creativity, views creativity as synonymous with chaos and disorder, and sees creative behavior as conflicting with academic and professional standards. Moreover, the myth that creativity is an innate trait or that only eccentric individuals can be creative further obstructs its acceptance and development within the field [6].

Creativity, defined as a problem-solving skill characterized by originality, fluency, flexibility, and elaboration, involves producing novel, high-quality, and aesthetically pleasing works that reflect the creator's values and beliefs. It is also associated with transformational thinking, which reinterprets existing knowledge or experiences into new forms and patterns [4], [6]. Badran [1] suggests that enhancing engineering creativity can directly influence the techno-economic progress of a community and therefore advocated for curricular reforms that include problem-solving tasks, risk-taking, and multidisciplinary activities that nurture creativity in engineering students.

Design activities in engineering programs are often related to synthesis exercises that follow known methodologies, except capstone design projects in the final year, which allow higher freedom in design. However, Kazerounian and Foley [5] argue that this is insufficient training for harvesting students' creativity. Keller [7] suggested that creativity is a learnable skill that can be enhanced through systematic instructional design. By creating active learning environments that adhere to accreditation standards, engineering instructional programs can effectively foster creativity [8]. Therefore, educators must integrate creativity-teaching strategies into engineering curricula to ensure students can practice and enhance their creative thinking within the classroom. Through this research, we aimed to address current issues with creativity teaching frameworks in engineering education by exploring new strategies combining the integration of multidisciplinary arts and engineering and the use of active learning in Virtual Reality (VR), which previous literature suggests are pedagogically supportive for nurturing creativity.

II. Literature Review

A. *Teaching Creativity through Integrated Art and Engineering Curriculum*

Research says employers are looking for individuals with specialized knowledge in their field and a diverse range of skills across multiple disciplines [2]. US universities' General Education coursework requirement falls short in preparing students for the full breadth of versatile careers employers seek. Often, separate courses fail to link different subject areas. Hence, a more integrated curriculum is needed to support knowledge, inquiry modes, and pedagogy from multiple disciplines [9].

Educational institutions have traditionally separated engineering and art education, where the former focuses on functionality and the latter on aesthetics. However, in today's technology-driven world, there is a need for innovative solutions that consider ethics, emotions, and human relationships. Therefore, the traditional education system needs to adapt so that STEM product developers can think critically about their decisions' impact on consumers' lives [10]. Educators are realizing the importance of integrating arts with STEM curricula to train students with scientific knowledge and humanistic discourse. Traditional STEM courses focused on finding a single solution through convergent thinking. However, adding arts to the curriculum teaches creativity, imagination, and exploration of solutions through multiple perspectives, known as divergent thinking. This engagement in the design process helps students gain a wider understanding of the subject and its applications [11].

The University of Georgia conducted a study that combined arts and engineering to teach creative thinking. Results showed that the multidisciplinary approach made learning more enjoyable, engaging, and emotionally stimulating for engineering students [12]. These potential benefits of combining science and arts education led institutions to investigate new curricula for STEM teaching with the integration of arts (STEAM approach, where A stands for Arts) [13], [14]. SUNY Potsdam and Lockheed Martin created a multidisciplinary curriculum combining biology, computer science, math, music, psychology, theater, visual arts, and vocal performance. The program included domain instruction, integrated learning, and problem-solving workshops. The curriculum advocated to produce leaders with strong communication, organizational, management, cross-disciplinary, divergent thinking, and self-awareness skills [15].

Even Nobel laureates often practice creative skills like visual arts, performing arts, crafts, photography, music, creative writing, etc. [16]. Correlation statistics and interviews have shown a positive relationship between creativity and academic achievement [17], [18].

The STEAM curriculum offers STEM students new domains and career paths to practice technological skills. Contemporary art has evolved beyond traditional techniques. Kinetic sculptures and interactive installations have bridged the gap between art and engineering, creating a multidisciplinary field [19]. Moritz Waldemeyer is an engineer-artist who creates bespoke installations for automobile brands and designs light-studded costumes for music artists [20]. Joris Laarman used 3D printing to create the world's first 3D-printed steel bridge, the MX3D Bridge, in Amsterdam [21]. Behnaz Farahi uses computational design and digital fabrication to create 3D-printed clothing that reacts to the wearer's environment, addressing issues like feminism and social interaction [22].

Educational institutions are integrating science, engineering, and arts coursework to provide creative learning avenues [23], [24]. However, there is little data on the learning outcomes of this approach [18], [25]. Therefore, this research aims to explore the use of a multidisciplinary curriculum integrating art and engineering to better understand the learning outcomes, focusing on the creativity construct.

B. Teaching Creativity through VR Environments

VR technology can take users to any location at any time, making the educational experience accessible and providing a safe space for practicing skills that otherwise would be ethically unsafe and costly to practice in the real world [25], [26]. VR offers many benefits in education due to its immersive visual graphics that make users feel physically present and encourage active participation in the learning process. The interactive 3D VR environments provide higher opportunities for engagement than traditional 2D tools [27]. According to constructivism learning theory, learning is improved when learners play an active role in learning and constructing knowledge based on their personal experiences through interaction with the world rather than through instruction that simply communicates knowledge [28]. Immersion in VR refers to the objective level of sensory fidelity a VR system provides because of its complex technologies that replace real-world sensory information with synthetic stimuli such as 3D visual imagery, spatialized sound, and force or tactile feedback [29]. Thus, highly immersive and interactive VR supports experiential learning as it gives learners greater agency over the learning process through interaction with the virtual world; consequently, the instructional design is highly student-centered. Students in the engineering disciplines need to develop the ability to visualize how objects behave spatially to develop problem-solving skills, and 3D visualization in VR has proven beneficial for improving learners' spatial understanding [30], [31], [32].

Creative thinking can be nurtured in a constructivist learning environment. Houtz and Krug [33] have explained how thinking is a constructivist process. They state that active involvement in the learning process facilitates higher-order thinking that is associated with creativity, while such cognitive aspects do not occur with just passive reception of instruction. According to the theory of constructivism, learning outcomes are improved when the instructional environments allow individuals to construct knowledge based on their personal experiences in the environments and prior knowledge structures. The affordances of VR - like immersion, embodiment, spatial learning, and interactivity, can actively engage learners in the learning process and potentially improve learning outcomes [27].

VR educational research has indicated some shortcomings in the study methods, such as the need for testing with a more diverse population, including higher education learners, exploring various learning topics, and longer interventions [18]. Due to the novelty of the VR technology, the need for a pre-exposure to the VR equipment before the actual study has also been suggested [34]. Even though promising, literature reviews on existing creativity research and the use of VR in education showed that research in these areas is scant and restricted to brief usages in non-controlled settings and lacks the integration of learning theories [26], [35]. Moreover, previous creativity research has mainly focused on understanding the creative personality, and evaluating environments conducive to creativity has been ignored [33]. Therefore, there was a need to understand what environments affect engineering students' creativity, which was explored in this research.

III. THEORETICAL FRAMEWORK

The theoretical framework of this research was based on constructivism, flow, and intrinsic motivation theories, and it guided the conducted research. Fig. 1 illustrates the research conjecture map, outlining how building kinetic sculptures in VR was believed to influence learning outcomes.

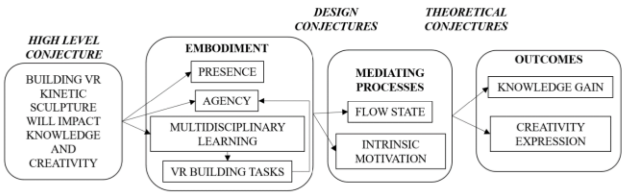

Fig. 1: Conjecture Map showing the theoretical framework of the research

The environment's embodied tasks included interacting with 3D models to understand multidisciplinary engineering dynamics and art concepts. It also had in-built tasks that allowed VR learners to apply what they learned to build kinetic sculptures. Harel and Papert [36] have noted that such activities improve learning outcomes by providing a situated context for the learning, which could create a desire to consciously construct knowledge structures to engage in the VR-building activity. According to the theory of situated cognition, individuals learn through context-driven experiences, "authentic activity" with the world [37]. Such context-driven learning through exploration rather than following a pre-established plan allows time to think, dream, gaze, get a new idea, try it, drop it, or persist. Such activities have been known to cause learners to engage in divergent thinking, a creativity trait [38]. Hence, these were considered the embodied features of the learning environment. Another assumption was that embodied STEAM learning can boost creativity by helping learners see how the different fields intersect. This learning approach has encouraged learners to apply their knowledge to fields outside their discipline [10], [11], [15], [24].

The CAMIL [39] VR model explains how embodiment, the feeling of owning a virtual body inside immersive VR, can occur due to the experience of presence and agency. VR's technological affordances, like immersion and interactivity, can lead to this embodiment. It was theorized that the developed VR environment could cause immersion and interactivity experiences by allowing the VR learners to explore the space through 3D model interactions using the left and right VR controllers for grabbing, placing, scaling, teleportation, etc. The environment was designed to be student-centered, as the learner would have the agency/autonomy to make decisions during the sculpture-building process through implicit interactions, such as if the sculpture does not move as desired or explicit interactions through audio/visual feedback. The sculpture building was meant for the assessment of creativity.

The research design conjecture was that the embodiment in the VR environment would cause mediating processes like the flow state and intrinsic motivation experience through the sculpture-building activity. A study was conducted to analyze the creativity factors of architecture and design education, focusing on two key elements - flow state and motivation. The research compared immersive VR and non-immersive learning environments and found that body involvement in immersive VR resulted in a more profound flow state and an elevated motivation to learn [40]. "Flow state" is a positive observational state that occurs when a person is completely involved in what she is doing in a way that makes her lose her sense of time. Some studies have shown a significant correlation between higher levels of flow and intrinsic motivation with higher levels of creativity [41], [42]. Hence, flow state and intrinsic motivation insights guided this research by considering how flow and intrinsic motivation can occur during the learning tasks.

Further supporting the mediating processes is Deci and Ryan's [43] self-determination theory (SDT). It defines intrinsic motivation as engagement in an activity because doing it causes a feeling of satisfaction. Per the SDT, intrinsic motivation depends on the learner's needs for autonomy and competence. Keller's [44] ARCS model explains that giving learners control over their learning can increase satisfaction. However, satisfaction can decrease when learners are forced to engage or are motivated by rewards. The interactive VR activities can support intrinsic motivation by initiating feelings of autonomy-satisfaction.

According to the SDT, the other supporting variable for intrinsic motivation is competence, which can come from how well the learner feels he can succeed in the learning tasks. Competence shares a connotation with the confidence construct of the ARCS model, which is defined as the belief in achieving success based on the ability to carry out actions [45]. Building kinetic sculptures in VR was expected to enhance learners' confidence and satisfaction, further supporting their intrinsic motivation.

Theoretical conjectures linked mediating processes to outcomes, with previous research demonstrating relationships between flow state and intrinsic motivation with knowledge gain and creativity [46]. Hence the focus was on evaluating this theoretical framework through the following research questions.

- What factors contribute to the sense of embodiment within a multidisciplinary VR learning environment?
- Why does embodiment during multidisciplinary VR learning mediate flow state and intrinsic motivation?
- What learning outcomes are observed using multidisciplinary VR learning regarding knowledge gain and creativity expression?

IV. METHODS

A. *Design-based Research Methodology*

We created a 3D interactive VR learning environment (educational technology) using Unity software and C# programming with a constructivist learning theory framework to address the research questions. The study used a design-based research methodology to view educational technology as a process. Challenges arise when comparing different media in studies, like attributing significant differences in learning outcomes to novelty and uncontrolled effects. Similar challenges arise in investigating the efficacy of VR educational interventions. The research used an exploratory approach, using qualitative strategies to gather and evaluate data. The aim was to develop a foundational framework for a multidisciplinary STEAM-based VR educational intervention, providing insights to inform further inquiry and real-life implementations of VR multidisciplinary curricula.

B. Context

The institutional review board of the University of Connecticut approved the research design and protocol for this study.

C. Participants

The seven students enrolled for the study (P1 to P7) were from two undergraduate courses from all four years from the Departments of Civil Engineering, Mechanical Engineering, and Multidisciplinary Engineering (MDE) at the University of Connecticut. Out of the seven participants, five were male, and two were female, with GPAs ranging from 2.4 to 3.92.

D. Design Tools and Tasks

Surveys show that engineering students are not often challenged to think creatively or innovatively. Evaluation assignments mainly involve solving traditional textbook problems, suggesting that faculty do not highly value creativity in today's engineering education [5]. We wanted the participants in the study to apply the engineering knowledge in a nontraditional way. The VR environment, therefore, was designed with the aim of teaching engineering dynamics with the integration of kinetic, assemblage, and optical art topics. Enrolled participants came for three consecutive visits during the Fall 2023 semester to complete the study procedure. Participants experienced the VR environment using the HTC Vive VR equipment, completed the assigned tasks in VR, and later participated in interviews to share their experiences. Each participant was run separately, requiring 21 VR sessions to complete the 7 individual 3-session protocols.

On each participant's first day, they were given a short tutorial on how to use the VR equipment, followed by Part 1 of the VR lesson, which consisted of an introduction to kinetic art (art with movement) and the rotational motion of rigid bodies (bodies moving in a circular path around a fixed axis), and the relation between the two. It also involved an introduction to rotational motion concepts of precession and gyroscopes. On the second day, each participant experienced Part 2 of the VR lesson, which consisted of examples of assemblage art (three-dimensional work of art made from combinations of materials including found or purchased objects) and gyroscope application in the Hubble space telescope. After the introduction to these topics through interactive models in the VR environment, the participant was exposed to a scenario where they are in (virtual) space, looking at the Hubble experiencing a malfunction of its gyroscopes. Participants were tasked with creating a disguised satellite replacement for the Hubble that would look like an artwork. They would have to apply the art-making techniques of assemblage art and later test the pointing control system by applying knowledge about gyroscopes and reaction wheels that were introduced to them earlier but in a different scenario. These learning activities aimed to allow the participants to apply engineering knowledge and think outside the box of normal scenarios to find solutions. On the third day, they completed the VR lesson's final part, which included an activity of creating an optical art painting by applying the concept of angular momentum conservation. The hands-on art-making approach was hoped to make learning more interesting and engaging.

E. Qualitative Instruments: Semi-structured Interviews

After the third VR session, each participant had a 30-45-minute semi-structured interview that was audio-recorded. They were asked about their previous experience with VR, engagement level, time perception, motivation levels, knowledge gain and creativity, challenges faced, and any additional feedback regarding the VR learning experience. Before use with participants, the interview questions were pilot-tested with an industrial design course instructor to check if the questions were understandable, and they facilitated the information flow to support data in line with the research.

V. Results

A. Demographics

The participants had varying levels of familiarity with VR technology. One participant mentioned that it was their first time experiencing VR and that they hadn't been exposed to it before due to the high cost of the equipment. The rest of the participants had prior experience with VR through gaming and other non-educational simulations. These experiences were at home, using HTC Vive or Oculus headsets, or at arcade venues.

Only a few participants were unsure what to expect from the VR session. Most assumed that the VR experience would involve the integration of engineering and art through the use of 3D models. This information was provided to them during the study's enrollment process, which shaped their expectations for the educational nature of the VR experience.

B. Thematic Codes

We analyzed the data collected from interviews using NVivo 14. We used both axial and open coding to find answers to our research questions and explore new theories generated from this exploratory research. The sections below cover the general themes observed for each research question. Some of the participants' responses were lightly edited for clarity.

1) Research Question 1: Why Embodiment was Experienced?

The VR environment seemed to elicit embodiment experiences in the participants. They reported psychological experiences of presence and agency, which have been mentioned in previous research as embodiment characteristics. Presence in terms of an experience in immersive VR has been defined as the feeling of being there. It is known to be affected by the level of immersion experienced, control factors like the degree, immediacy, and mode of control allowed by the VR technology, and the representational fidelity of the VR [39]. Immersion and a sense of solitude and focus were reported as factors contributing to the participants' feeling of presence.

a) Immersion: Participants talked about the relaxing background music and audio feedback in the VR environment that made them feel that they were not being bogged down with a lot of information, giving them a feeling of being completely immersed in the learning environment. P3 expressed feeling the VR environment as

"I found myself deeply engaged in a play within my thoughts and psychology. I felt so involved in it that I wanted to experience it fully, step by step. It almost felt like my brain was completely convinced that I was actually in that environment and fully present there," which shows that this participant experienced presence in the virtual world through immersion, a characteristic of embodiment.

b) Sense of Solitude and Focus: Another theme associated with participants' feeling of presence was the sense of solitude and focus experienced in the environment. The participants were more attentive during the learning because they felt like there was less distraction because they were alone in the VR environment. As noted by P2, "You are in a situation where you don't have to worry about other people in your space. You're not bothered by anyone. You're not like bogged down by having people talking next to you," which reflects the learning experience was positive because it eliminated distractions. P3 further reinforced this theme by saying, "Because it separates everyone who gets in this environment from outside life and makes you focus 100% on what you have in your hand and what you wanted to do and the task you need to learn." The research participants have stated that experiencing solitude with the help of technology can benefit learning. However, it's essential to consider that VR experiences like the Apple Vision Pro have been criticized for causing isolation from the real world. Patel [47] mentioned that "the Vision Pro is such a lonely experience, regardless of the weird ghost eyes on the front. You're in there, having experiences all by yourself that no one else can take part in." Hence, VR's usefulness must be considered on a case-by-case basis. The VR learning in this research's case was perceived as more interesting, which led to a higher focus on the learning material. Even if it was designed as a single-user educational experience, the lack of a learning partner did not negatively affect learning, as the participants stated. One of the problems of students' lack of engagement is that instructional content is often not presented in a way that motivates students to engage cognitively. According to information processing theory, materials capable of capturing students' attention are more likely to be retained as a function of memory. The dual store model suggests that the learner's attention and recognition are necessary for information to pass from the sensory register to the working and long-term memory [48]. The instructional material presented in this study seemed to increase attention, engagement, and focus compared to previous learning experiences in other regular classes, as specified by P2: "I was alone 3D building instead of watching or drawing. This environment eliminated distractions, allowing 100% focus on the task at hand."

Agency is another characteristic of embodiment that was noted to be experienced in the VR learning environment. According to the CAMIL model, immersive VR that allows the user to control the parameters of the environment through interaction, creates a higher sense of agency for the user [39]. In this research, factors that pointed to the experience of agency were curiosity and enjoyment due to interaction.

a) Curiosity: Epistemic curiosity is defined as having a drive to know because of a knowledge gap. This drive is caused when participants are introduced to thematic probes and strange, surprising, or puzzling situations or questions [49]. While engaging with the VR intervention, P1 mentioned, "It's almost mysterious," which piqued their epistemic curiosity for exploring. Furthermore, one participant mentioned that they were driven to explore the learning, "What do the sliders do? Let me move these sliders. It's a thing with my brain where I see something that's pushable, and I need to push it."

b) Enjoyment due to Interaction: Participants also expressed that VR learning was more enjoyable than learning in a traditional class, as described by P1: "Interacting with the simulation, exploring the environment, and manipulating the levers made learning enjoyable." P4 also noted the benefits of this interactivity in VR: "I preferred learning in VR because it was more playful and less rigid than traditional classrooms focused on memorization. I love being in an active space where I can move around. It's liberating to be active with my body and mind outside my usual sitting classes." Literature shares that active engagement during learning enhances agency and facilitates the construction of knowledge structures [50], and the study participants noted similar experiences.

2) Research Question 2: Why Flow State was Experienced?

According to the flow theory, there is a feeling of time transformation during the flow state experience. Participants expressed a loss of time consciousness in VR, P2: "No time reference, no phone or watch. Fully immersed in a different reality, time passes differently. Too focused to notice a clock, like taking an exam and time flies." P6 expressed time moving faster: "It seemed to pass quickly because I was engaged and interested in what I was doing." These statements indicate that the participants experienced time transformation, which is one of the constructs of the flow theory [41], suggesting that flow state was experienced in this educational environment.

3) Research Question 3: Why Intrinsic Motivation was Experienced?

The interviews highlighted themes like control, the relevance of art and engineering integration, satisfaction, and interest in self-directed and project-based multidisciplinary learning as factors contributing to the intrinsic motivation felt during VR learning.

a) Control: Most participants expressed feeling in control during the learning process because they could explore the material at their personal learning pace. For instance, P6 stated, "I had control of the learning because I was able to work at my own pace, and it was different because it was more one-on-one, like me with myself rather than, like me listening to a teacher talk to 30 plus other people." P2 talked about having the freedom and ability to delve deeper into the subject matter at their own will: "If I wanted to delve into a topic in greater detail, I had the option to review it. I could also rewind or fast-forward. This approach enabled me to study the areas that were unclear to me and revise the material. It was more enjoyable." These statements highlight that greater control over the learning intrinsically motivated the participants to pursue the learning.

b) Relevance of art and engineering integration: Examples of intrinsic motivation occurrence were observed when participants realized and appreciated the connection between art and engineering fields and expressed a desire to explore the topics further after completing the learning module. Two participants, P2 and P4, from the MDE – industrial design major, shared that they saw the interconnectedness between the art and engineering fields through the kinetic sculptures and became interested in exploring the topic further in the future. Like P2 said, referring to the optical art-making task shown in Fig. 2, "Using math to guide the flow of a painting fascinates me. Art and engineering are interconnected, and knowledge gained in one field can enhance the other. Even small visual details can improve a mechanical project. Creating sculptures in VR is worth exploring, even for those who oppose it." P4 had a similar observation: "I learned about the physics of kinetic sculptures and how factors like torques and angular momentum come into play when building moving artworks. Introducing kinetic sculptures as a topic for discussing basic elements of physics was a great idea, as it highlights the interdisciplinary nature of these artworks." Both of the participants had interests in an interdisciplinary career that integrates art and engineering and could see how the learning introduced in this study was relevant for their future careers, and that increased their motivation to pursue it, highlighting the role of relevance, which is also noted in the ARCS model [44].

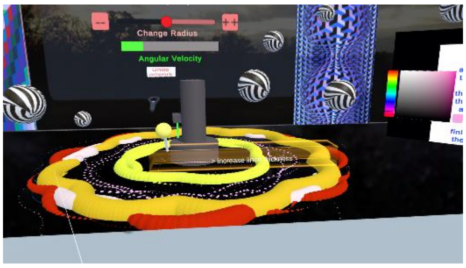

Fig. 2: Optical art-making in VR using engineering concepts

c) Satisfaction: According to SDT, intrinsic reinforcement is more effective than extrinsic reinforcement in boosting motivation. When students feel they understand the topic, they experience satisfaction, leading to internal learning motivation [43]. P2 said building sculptures and kinetic paintings in VR by applying the concepts felt more rewarding than just doodling in a notebook. This rewarding/ satisfying feeling resulted from completing tasks and gaining a deeper understanding of the learning topics. Unlike Skinner's theory of operant conditioning [51], which uses positive and negative reinforcements and punishments to shape behavior, VR instruction supports intrinsic motivation development by helping participants feel inherent satisfaction in the learning process [43].

d) Interest in Self-directed and Project-based Learning: Knowles's [52] andragogy theory describes that adult learning is self-directed and problem-centered. In this research with undergraduate adult learners, it was observed that the absence of social interaction in VR was a cause of internal motivation. P5 said, "Experimenting with everything was enjoyable. I was in my own private world with the freedom to do anything." According to the adult learning theory, adult learners prefer being self-directed instead of relying on others to guide their learning. It was learned from the curriculum that it helped participants reflect at a meta level about what they are learning, as was pointed out by P4: "I spent a bit of time focusing on what was the purpose of making the three days, and then I was like okay, now that I kind of know what I'm doing I should like, do the assignments and see if I understand them." Also, participants appreciated the project-based multidisciplinary activities. P2 mentioned, "I think anything that mixes engineering and art is fascinating. There's not enough of that. And just being able to take something you learn in class and apply it artistically and differently from what you would normally do in an engineering class is just refreshing, and I'm all for it." This statement highlights that the student found applying the engineering knowledge in an art project interesting and, therefore, was motivated to engage in the learning. The hands-on aspect was also a cause of intrinsic motivation, as was noted by P4: "I think it's a lot more comparable to when people say they learn hands-on; I think this is closer to what they mean like more visual representations and more intuition-based learning compared to... I'm harping on the physics equations thing, but the biggest contrast here was that this was a very touch-see-learn experience where you get your intuition or sense of how things work a lot better rather than your number crunching."

4) Research Question 4: What were the Learning Outcomes?

The study investigated two outcomes: the effects on 1. Engineering and Art content knowledge, and 2. Creativity development. Participants reported that interacting with 3D models in VR and contextualizing the learning using a multidisciplinary approach improved their understanding of the learning topics.

a) Knowledge gain due to interaction with 3D models: With respect to knowledge, participants mentioned VR improved their understanding of the concepts through the 3D models that they could interact with in the environment. P1 shared his experience with learning the concept of precession: "On Day 1 of the sculpture project, we were able to apply force to the arm, which then applied torque to the rotating gyroscope. This helped me understand precession in a way that I hadn't before. Although I had worked in a manufacturing plant that made gyroscopes, we only got a PowerPoint presentation on precession. By modifying the sculpture's parameters, I could visualize what happens when a gyroscope precesses. It also helped me understand why every gyroscope will precess because there's always a little torque on it. Having a physical model of it was great because, in a classroom setting, there isn't as much time to play with it as in a VR environment, where you have more freedom to interact with it. It was a pretty cool thing to be able to do." P4 mentioned that the 3D interaction made it more intuitive to understand abstract concepts they had found difficult to understand in 2D learning: "Torque was hard to understand in my physics class, but it became intuitive when I experimented with an actual object in 3D space. I can now apply it better to problems involving 3D objects and torque." Thus, based on participant feedback, it appeared that incorporating interactive visual aids into engineering topics was highly beneficial.

b) Multidisciplinary Curriculum provided Context: During the interview, participants were asked about their experience learning in a multidisciplinary way and applying both engineering and art knowledge to complete the sculpture-building task. P4 answered, "Art allowed me to contextualize the physics I was learning. While making the sculpture, I had to consider the underlying physics principles. This forced me out of my comfort zone, confronting concepts like kinetic sculptures and optical illusions, and ultimately leading me to engineering principles." According to Jasper adventure experiments, presenting learners with "what if" questions through stories helps them to be flexible in contextualizing learning in different scenarios, and helps them to integrate and transfer knowledge from multiple fields to answer a question [53]. In this study, that question was, what if the Hubble breaks down, and you need to create a replacement satellite that looks like an assemblage sculpture but is also functional with a pointing system consisting of gyroscopes and reaction wheels. Based on the participants' answers in the interview, it was observed that the narrative context of the Hubble was beneficial for the transfer of art and engineering knowledge.

c) Multidisciplinary Curriculum Reduced Stress: The multidisciplinary education approach improved participants' learning experience. When asked about their engineering learning experience with art integration, participants noted it was less stressful and enjoyable: "Artistic learning is less stressful and more interesting than traditional classrooms." With the introduction of art, there was an element of surprise in the learning, which participants found interesting: "an unexpected way of learning."

d) Learning art concepts: When asked what they learned in the VR experience, P6 mentioned, "I learned about the history of kinetic sculptures, who invented them, and how they work." After the VR experience, P4 reflected on his strategy while building the sculpture: "I think the biggest one I was thinking of was color and how it was shown in space. For sculpture, I think my goal was simplifying the sculpture's form." P7 also shared, "I was trying to use complementary colors to enhance the visual appeal of my sculpture." These statements indicate that engineering students were focused on learning about the art history of kinetic sculptures and were also striving to apply art concepts, such as the elements and principles of design, to create more appealing sculptures.

The semi-structured interview questions employed creativity self-assessments to understand participants' beliefs about their own creativity in the context of this study. The themes highlighted were that creativity was improved because of the experimentation allowed in VR and that the narrative storyline of the environment impacted participants' creativity.

a) Improved Creativity due to Experimentation: In the interview, the participants were also asked to compare the learning tasks in this research with their previous learning experiences, and they mentioned that certain aspects of the multidisciplinary VR mode were better than learning in regular classes because it allowed them to think more openly of solutions and also give them the ability to experiment, both of which in their opinion helped them to be more creative. According to P2, "It's like a project where you're given a task but can come up with your own approach. For example, while designing the Hubble sculpture. Different people may create something that looks more organic but serves the same purpose." Studies conducted to investigate the obstacles to creativity development in engineering courses have highlighted that the absence of open-ended assessments that encourage divergent thinking is a major issue [4]. The research findings underscored the significance of this problem.

Engineering students in the past have stated that they would be more creative if they could experiment and take more risks in their curricular projects, allowing them more freedom to practice creativity [5]. This research's participants also thought that the experimentation allowed during sculpture building helped them to be more creative. One such instance was noted by P4, who stated that they can build something with more artistic freedom as they need not consider the laws of physics, "VR offers more creative freedom than the physical world. In VR, artists can ignore the laws of physics and push their creativity beyond what is possible in real life. For instance, sculpting in VR requires no consideration of gravity, allowing artists to create objects not limited by the laws of physics." P7 thought, "I liked the color selection system and the ability to work with larger formats. It's expensive and difficult to find resources for large format works, but the virtual environment allowed me to use infinite materials and work on an unlimited scale." Some participants, like P1, attempted the VR tasks multiple times with a different approach each time: "The first time, I was very focused on the learning objective. The second time going through things, I felt more creative because I knew how to operate the interface. I could just play around and have things go directly from my brain to what's in the VR environment." This quote informs that multiple attempts at the problems in VR enhanced the creative thinking processes.

b) Impact of narrative context on creativity: Another finding was the impact of narrative on creativity. Research says that instruction presented with a storyline/ narrative provides a context for learning and has better learning outcomes due to increased motivation. These have been attributed to increased presence, self-efficacy, interest, and perception of control [5]. P4's statement below emphasizes how the Hubble narrative impacted the creative decisions he made while building the sculpture: "I believe that when creating scenarios for people to work with, the scenario itself can heavily influence the ideas that come to mind. For example, when working on the gyroscope activity with the scenario of Hubble in space, I thought about rocketships much more than if I had simply been given the tools without any context." This particular statement refers to how the introduction to being in extraterrestrial space around the Hubble influenced the student's creative decision to build a sculpture that looks like a rocketship (Fig. 3). In the book "How People Learn," the authors explain how previous experiences affect transfer because sometimes learning new information becomes difficult if there is a solid pre-existing knowledge base [54]. In this case, it was observed that the student's creativity was limited due to their prior knowledge base of space and rockets developed after experiencing the presented narrative. Despite being tasked to create an artwork that did not resemble a space machine or satellite, the student could not register this information due to pre-existing schemas developed from the narrative.

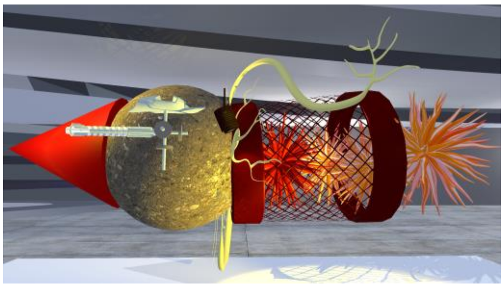

Fig. 3: Rocketship inspired VR sculpture

VI. Limitations, challenges, and feedback

The VR environment developed for this study had some limitations that posed challenges to learning. Firstly, the program only allowed the user to teleport on the floor level of the environment, which precluded an aerial view and made it difficult for some participants to see everything they wanted to. Secondly, it was suggested that having an interactive mathematical equation alongside the interactive models would make the VR environment more engineering-oriented. Additionally, the VR program was a single-user experience, which some participants felt was not learning-conducive. Research has shown that learning can be effective as a social activity that requires regular interaction with a community of practice [55]. Thus, future studies should aim to make multidisciplinary VR experiences multiuser or provide additional collaborative learning experiences, such as collaborative discussions on learning management system (LMS) platforms, to engage learners in a social learning setting.

Another challenge was the novelty of the VR equipment. As many of the participants were using the equipment for the first time, they found it initially difficult to learn the VR controls. Not having fluent VR users may have limited the learning outcomes. One of the participants, P3, compared the experience to driving in New York City, where you need to have more than one set of eyes to keep track of everything around you. Another participant, P5, said that getting used to the controls took some time. This novelty might have affected their learning experience with this medium. Participants also reported some initial discomfort after wearing the VR headsets, which disappeared as they spent more time in the experience. One participant mentioned they were already stressed because it was the midterm exam week when they participated in this research study. They felt that being in a stressful state of mind in VR aggravated the stress and made them experience cybersickness.

VII. Conclusion

This research paper proposed that a multidisciplinary VR learning environment could benefit undergraduate students' creativity development. Preliminary findings suggested that the proposed learning environment positively influenced creative performance in cross-disciplinary visual arts and engineering topics. Participants noted heightened embodiment, flow, and intrinsic motivation. Feelings of presence and agency characterized embodiment in VR. Flow states were induced as participants lost the sense of time, with the perception of time moving faster in VR. Intrinsic motivation stemmed from feelings of confidence, relevance, and satisfaction in the learning tasks, validating constructs of constructivism, SDT, and Keller's motivation model. Self-directed and project-based learning also supported intrinsic motivation development. The beneficial outcomes of the reported learning environment included knowledge gain and a higher creativity expression because of improved spatial visualization, divergent thinking, and experimentation. It was also learned that narrative of the environment affected creativity. Some participants struggled with VR learning due to its novelty, the equipment learning curve, the negative impact of pre-existing stress, and the desire for multiuser collaborative sessions.

Future research on VR should recruit skilled VR users, expand the sample size of participants, and extend the interaction time. Quantitative instruments like pretests-posttests, surveys and creativity tests can validate results [46]. Although the small sample size limits generalizability, the qualitative results from this research have generated testable hypotheses for further quantitative randomized control trials using survey instruments. They lay the groundwork for STEAM and interactive VR pedagogy to contribute to creativity development. The findings highlight the positive impact of VR and multidisciplinary instruction in engineering, offering a basis for innovative teaching practices.

References

[1] I. Badran, "Enhancing creativity and innovation in engineering education," *Eur. J. Eng. Educ.*, vol. 32, no. 5, pp. 573–585, Oct. 2007, doi: 10.1080/03043790701433061.

[2] H. R. Associates, "Falling short? College learning and career success," *Assoc. Am. Coll. Univ.*, 2015, Accessed: Mar. 06, 2024. [Online]. Available: https://www.voced.edu.au/content/ngv:78305

[3] A. Furman, "Teacher and Pupil Characteristics in the Perception of the Creativity of Classroom Climate," *J. Creat. Behav.*, vol. 32, no. 4, pp. 258–277, Dec. 1998, doi: 10.1002/j.2162-6057.1998.tb00821.x.

[4] J. C. Kaufman, *Creativity 101*. Springer publishing company, 2016.

[5] K. Kazerounian and S. Foley, "Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perceptions," *J. Mech. Des.*, vol. 129, no. 7, pp. 761–768, Feb. 2007, doi: 10.1115/1.2739569.

[6] J. A. Plucker, R. A. Beghetto, and G. T. Dow, "Why Isn't Creativity More Important to Educational Psychologists? Potentials, Pitfalls, and Future Directions in Creativity Research," *Educ. Psychol.*, vol. 39, no. 2, pp. 83–96, Jun. 2004, doi: 10.1207/s15326985ep3902_1.

[7] J. M. Keller, "Tools to Support Motivational Design," in *Motivational Design for Learning and Performance*, Boston, MA: Springer US, 2010, pp. 267–295. doi: 10.1007/978-1-4419-1250-3_11.

[8] D. Pusca and D. O. Northwood, "Curiosity, creativity and engineering education," *Glob. J. Eng. Educ.*, vol. 20, no. 3, pp. 152–158, 2018.

[9] A. Bear and D. Skorton, "The world needs students with interdisciplinary education," *Issues Sci. Technol.*, vol. 35, no. 2, pp. 60–62, 2019.

[10] G. Innella and P. A. Rodgers, "The benefits of a convergence between art and engineering," *HighTech Innov. J.*, vol. 2, no. 1, pp. 29–37, 2021.

[11] M. H. Land, "Full STEAM ahead: The benefits of integrating the arts into STEM," *Procedia Comput. Sci.*, vol. 20, pp. 547–552, 2013.

[12] T. Cotantino, N. Kellam, B. Cramond, and I. Crowder, "An Interdisciplinary Design Studio: How Can Art and Engineering

Collaborate to Increase Students' Creativity?," *Art Educ.*, vol. 63, no. 2, pp. 49–53, Mar. 2010, doi: 10.1080/00043125.2010.11519062.
[13] "Electrical Engineering (Media Arts and Sciences), MS - MS | Degree Details | ASU Degree Search." Accessed: Mar. 06, 2024. [Online]. Available: https://degrees.apps.asu.edu/masters-phd/major/ASU00/ESAMEMS/electrical-engineering-art-media-and-eng-ms?init=false&nopassive=true
[14] © Stanford University, Stanford, and California 94305, "Art + Tech – Stanford Arts." Accessed: Mar. 06, 2024. [Online]. Available: https://arts.stanford.edu/for-faculty/art-tech/
[15] M. E. Madden *et al.*, "Rethinking STEM education: An interdisciplinary STEAM curriculum," *Procedia Comput. Sci.*, vol. 20, pp. 541–546, 2013.
[16] R. Root-Bernstein, "Arts and crafts as adjuncts to STEM education to foster creativity in gifted and talented students," *Asia Pac. Educ. Rev.*, vol. 16, no. 2, pp. 203–212, Jun. 2015, doi: 10.1007/s12564-015-9362-0.
[17] Y. Nami, H. Marsooli, and M. Ashouri, "The relationship between creativity and academic achievement," *Procedia-Soc. Behav. Sci.*, vol. 114, pp. 36–39, 2014.
[18] G. Ozkan and U. Umdu Topsakal, "Investigating the effectiveness of STEAM education on students' conceptual understanding of force and energy topics," *Res. Sci. Technol. Educ.*, vol. 39, no. 4, pp. 441–460, Oct. 2021, doi: 10.1080/02635143.2020.1769586.
[19] M. Smyth, *Digital blur: creative practice at the boundaries of architecture, design and art*. 2010. Accessed: Mar. 06, 2024. [Online]. Available: https://napier-repository.worktribe.com/output/210593
[20] "Studio Waldemeyer." Accessed: Mar. 06, 2024. [Online]. Available: https://waldemeyer.com/
[21] "MX3D Bridge," Joris Laarman. Accessed: Mar. 06, 2024. [Online]. Available: https://www.jorislaarman.com/work/mx3d-bridge/
[22] "Clothes react to your environment," *BBC News*. Accessed: Mar. 06, 2024. [Online]. Available: https://www.bbc.com/news/av/technology-36905314
[23] "Brown-RISD Dual Degree Programs and Shared Resources | RISD." Accessed: Mar. 06, 2024. [Online]. Available: https://www.risd.edu/academics/risd-brown-programs-and-opportunities
[24] A. Ventura, "MIT students create original kinetic art," MIT News | Massachusetts Institute of Technology. Accessed: Mar. 06, 2024. [Online]. Available: https://news.mit.edu/2014/mit-students-create-original-kinetic-art
[25] D. M. Antonacci and N. Modaress, "Envisioning the educational possibilities of user-created virtual worlds," *AACE Rev. Former. AACE J.*, vol. 16, no. 2, pp. 115–126, 2008.
[26] M. Soliman, A. Pesyridis, D. Dalaymani-Zad, M. Gronfula, and M. Kourmpetis, "The application of virtual reality in engineering education," *Appl. Sci.*, vol. 11, no. 6, p. 2879, 2021.
[27] Y. Song and L. Li, "Research on application of VR technology in art design teaching," in *2018 International Conference on Engineering Simulation and Intelligent Control (ESAIC)*, IEEE, 2018, pp. 343–345. Accessed: Mar. 06, 2024. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/8530429/
[28] D. Cunningham and T. Duffy, "7. Constructivism: Implications for the Design and Delivery of Instruction", Accessed: Mar. 12, 2024. [Online]. Available: https://homepages.gac.edu/~mkoomen/edu241/constructivism.pdf
[29] D. A. Bowman and R. P. McMahan, "Virtual reality: how much immersion is enough?," *Computer*, vol. 40, no. 7, pp. 36–43, 2007.
[30] S. Hsi, M. C. Linn, and J. E. Bell, "The Role of Spatial Reasoning in Engineering and the Design of Spatial Instruction," *J. Eng. Educ.*, vol. 86, no. 2, pp. 151–158, Apr. 1997, doi: 10.1002/j.2168-9830.1997.tb00278.x.
[31] J. Fogarty, J. McCormick, and S. El-Tawil, "Improving Student Understanding of Complex Spatial Arrangements with Virtual Reality," *J. Prof. Issues Eng. Educ. Pract.*, vol. 144, no. 2, p. 04017013, Apr. 2018, doi: 10.1061/(ASCE)EI.1943-5541.0000349.
[32] A. Z. Sampaio, M. M. Ferreira, D. P. Rosário, and O. P. Martins, "3D and VR models in Civil Engineering education: Construction, rehabilitation and maintenance," *Autom. Constr.*, vol. 19, no. 7, pp. 819–828, 2010.
[33] J. C. Houtz and D. Krug, "Assessment of creativity: Resolving a mid-life crisis," *Educ. Psychol. Rev.*, vol. 7, no. 3, pp. 269–300, Sep. 1995, doi: 10.1007/BF02213374.
[34] M. Bricken, "Virtual reality learning environments: potentials and challenges," *ACM SIGGRAPH Comput. Graph.*, vol. 25, no. 3, pp. 178–184, Jul. 1991, doi: 10.1145/126640.126657.
[35] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, "A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda," *Comput. Educ.*, vol. 147, p. 103778, 2020.
[36] S. Papert and I. Harel, "Situating constructionism," *constructionism*, vol. 36, no. 2, pp. 1–11, 1991.
[37] J. S. Brown, A. Collins, and P. Duguid, "Situated cognition and the culture of learning," *1989*, vol. 18, no. 1, pp. 32–42, 1989.
[38] J. P. Guilford, "Creativity: Yesterday, Today and Tomorrow," *J. Creat. Behav.*, vol. 1, no. 1, pp. 3–14, Jan. 1967, doi: 10.1002/j.2162-6057.1967.tb00002.x.
[39] G. Makransky and G. B. Petersen, "The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality," *Educ. Psychol. Rev.*, vol. 33, no. 3, pp. 937–958, Sep. 2021, doi: 10.1007/s10648-020-09586-2.
[40] S. Obeid and H. Demirkan, "The influence of virtual reality on design process creativity in basic design studios," *Interact. Learn. Environ.*, vol. 31, no. 4, pp. 1841–1859, May 2023, doi: 10.1080/10494820.2020.1858116.
[41] M. Csikszentmihalyi, "The flow experience and its significance for human psychology," *Optim. Exp. Psychol. Stud. Flow Conscious.*, vol. 2, pp. 15–35, 1988.
[42] R. MacDonald, C. Byrne, and L. Carlton, "Creativity and flow in musical composition: an empirical investigation," *Psychol. Music*, vol. 34, no. 3, pp. 292–306, Jul. 2006, doi: 10.1177/0305735606064838.
[43] R. M. Ryan and E. L. Deci, "Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being.," *Am. Psychol.*, vol. 55, no. 1, p. 68, 2000.
[44] J. M. Keller, "Development and use of the ARCS model of instructional design," *J. Instr. Dev.*, vol. 10, no. 3, pp. 2–10, Sep. 1987, doi: 10.1007/BF02905780.
[45] A. Bandura, "Self-efficacy: toward a unifying theory of behavioral change.," *Psychol. Rev.*, vol. 84, no. 2, p. 191, 1977.
[46] T. M. Amabile, "Motivation and creativity: Effects of motivational orientation on creative writers.," *J. Pers. Soc. Psychol.*, vol. 48, no. 2, p. 393, 1985.
[47] N. Patel, "Apple Vision Pro review: magic, until it's not," The Verge. Accessed: Mar. 12, 2024. [Online]. Available: https://www.theverge.com/24054862/apple-vision-pro-review-vr-ar-headset-features-price
[48] R. C. Atkinson and R. M. Shiffrin, "Human memory: A proposed system and its control processes," in *Psychology of learning and motivation*, vol. 2, Elsevier, 1968, pp. 89–195. Accessed: Mar. 13, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0079742108604223
[49] D. E. Berlyne, "A theory of human curiosity," 1954, Accessed: Jan. 29, 2024. [Online]. Available: http://www.todmanpsychology.com/s/A-Theory-of-Human-Curiosity-Berlyne-1954.pdf
[50] M. C. Johnson-Glenberg, "The Necessary Nine: Design Principles for Embodied VR and Active Stem Education," in *Learning in a Digital World*, P. Díaz, A. Ioannou, K. K. Bhagat, and J. M. Spector, Eds., in Smart Computing and Intelligence. , Singapore: Springer Singapore, 2019, pp. 83–112. doi: 10.1007/978-981-13-8265-9_5.
[51] B. F. Skinner, "Operant behavior.," *Am. Psychol.*, vol. 18, no. 8, p. 503, 1963.
[52] M. S. Knowles, "From pedagogy to andragogy," *Relig. Educ.*, 1980, Accessed: Mar. 13, 2024. [Online]. Available: https://colllearning.info/wp-content/uploads/2019/03/The-Modern-Practice-of-Adult-Education.pdf
[53] J. D. Bransford, *The Jasper project: Lessons in curriculum, instruction, assessment, and professional development*. Routledge, 2013. Accessed: Mar. 13, 2024. [Online]. Available: https://www.taylorfrancis.com/books/mono/10.4324/9781315045207/jasper-project-john-bransford
[54] National Research Council, "How People Learn: Brain, mind, experience, and school," *Natl. Acad. Press*, 2000, Accessed: Mar. 04, 2024. [Online]. Available: https://teaching.sites.ucsc.edu/wp-content/uploads/sites/45/2016/09/RS-7-HPL1.pdf
[55] J. Lave and E. Wenger, *Situated learning: Legitimate peripheral participation*. Cambridge university press, 1991.