Enhancing Design Education Through Spatial Computing: A Comparative Study of Traditional and Immersive Technologies in Chair Design Projects

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***Abstract*—This innovation practice explores whether using spatial computing technologies in the form of the Apple Vision Pro and Nomad Sculpt in a mixed-reality environment affects student outcomes on learning goals and creative expression in the context of a chair design project in design education. The primary hypothesis of the study is that, even though students are provided with the exact project specifications, goals, and assessment rubrics, student design outcomes on learning goals and creative expression in the chair design project will improve when using the Apple Vision Pro and Nomad Sculpt as opposed to traditional digital design technologies (the control group using iPads and Nomad Sculpt). In the chair design project, learning goals and course outcomes were framed around projects that included mass, support, openings, shape expression, technical articulation, conversation, structure, sustainability, form, and fulfillment. On average, the subset of students using the Apple Vision Pro and Nomad Sculpt reported more intuitive, immersive, and creative experiences in the design process and the resulting chair designs in reflective essays. These findings are mainly based on quantitative measures of flexibility, idea originality, idea execution, depth of conceptual understanding, engagement, and qualitative measures of experiences through surveys and interviews. Developing an understanding of these tools to provide rich, relevant feedback and enabling productive critique and implementation on the device seems almost insurmountable hurdles due to access, new technologies' learning curve, and the inefficiency of integrating spatial computing tools into pedagogical frameworks. Overall, the research highlights the critical pedagogical advantages of using spatial computing technologies such as the Apple Vision Pro in design education, particularly in design fields requiring high visual-spatial aptitude levels. Furthermore, it provides guidelines for future research into the educational merits of immersive technologies and argues that we need to move beyond the predominantly uni-directional pedagogical models that have characterized the field for more than half a century. This study illustrates the potential of spatial-computing tools to enhance creative problem-solving and the substantial merits for future research into its broader educational applications.**

***Index Terms*—Spatial Computing, Design Education, Virtual Reality**

I. Introduction

The process of how design education has evolved over the past few decades is quite intriguing. Design education nowadays has become much more sophisticated and innovative, with technology being infused into the curriculum. This digitalization of design, throughout the years, has provided much more dynamic, interactive, and personalized learning experiences. Traditional digital design tools can be traced back to the early use of computer-aided design (CAD) software. This enables students to create a view of designed products in both two and three dimensions. However, with the current technology at our fingertips that has continued to innovate throughout the years, there is now a call for us to explore more immersive and intuitive prototyping tools to enable a more impactful learning process of design education.

Spatial computing, which overlays physical and digital realities, can also allow students to create and manipulate 3D models in real time through unique immersive digital spaces. The Apple Vision Pro and the software Nomad Sculpt are at the forefront of this technology, offering an immersive, intuitive environment where design students can interact with digital objects as physical objects in real-time. Spatial computing can also enhance design education because it allows students to use their sensory abilities more effectively. Students can conceptualize, visualize, and interact with their designs in a way that can lead to better understanding and design.

Even though there is much promise in spatial computing for design education, more empirical research is needed to explore its efficacy. This study addresses that research gap by looking at learning outcomes and creative expression related to two chair design projects and topics: imagination and ideas and ergonomics. The specific research question of this study assesses how successful design outcomes and creative expression by students will differ when using spatial computing technologies (such as the Apple Vision Pro and Nomad Sculpt) with the exact project specifications, compared with those using more conventional digital 2D or 3D design technologies. The hypothesis is that users of spatial computing tools will exhibit more significant levels of successful design completion and creative expression than users of the 2D and 3D tool groups.

This innovation practice explores the pedagogical benefits of spatial computing in design education, focusing on chair design projects. By comparing traditional digital design methodologies with spatial computing approaches, the study seeks to provide empirical evidence on the enhanced learning and creative outcomes facilitated by immersive technologies. The significance of this research lies in its potential to inform and guide future pedagogical strategies in design education, ensuring that they are aligned with the evolving technological landscape and cater to the needs of the next generation of designers.

II. Related Works

A. Spatial Computing as a Tool

The concept of spatial computing, referring to technologies that allow humans to interact in three-dimensional space with digital or virtual content has been of growing interest in academia as well as industry [1]. According to Benford and Fahlén: Spatial computing is a collection of processes for imaging, modelling, deciphering, and interacting with the physical and virtual space that surrounds us [2].Accelerating conversations in this regard are recent innovations, especially the advent of augmented reality (AR) and virtual reality (VR) technologies. For example, in an early formative text, Papagiannis define AR as 'a set of technologies that allow for the augmentation of the physical world with digital information [3]. This augmentation is performed in real-time as the user interacts with the environment.' Similarly, Lungu with colleagues discussed the 'triangle of mixed reality', which conceptualised the continuum between the physical and the virtual worlds, which is a fundamental construct underpinning much of the mechanics and implications of spatial computing [4].

B. Importance of Spatial Computing to Design Education

As design education shifts towards spatial computing, so too do design paradigms. In a study investigating the potential of VR tools in architectural education, Bhatt and Freksa argued that immersive spatial experiences let learners perceive and interact with a room at a scale closer to their own bodies and, as such, they are more conducive to spatial reasoning, an important skill for designers in many fields [5]. Several studies further investigated the added value of AR tools in bridge the gap between abstract knowledge and practical training via provide real-time interactive feedback, which is usually missing in regular educational settings. This feedback loop might also be useful in design education, where spacial and visual adjustments happens frequently and iteratively [6]–[8].

C. Advantages of Spatial Computing in Design Education

The advantages of using spatial computing for design education are manifold and relate to better interaction, better spatial understanding, and better communication of ideas. A study showed that AR is more effective for learning because it is fun and interactive, two characteristics that are of paramount importance when it comes to stimulating motivation and engagement in creative tasks – of vital relevance in the field of design education [9]. A study by Rossano indicates that the use of AR tools for learning geometry and spatial cognition actually works, and that skills and spatial models of how objects relate to each other are retained and used the following day after practice [10]. Last but not the least, a study by Knoll and colleagues points to an aspect that is of great importance in teamwork and collaboration – both values that are at the core of the design profession [11]. This study shows that the potential of spatial computing will make it possible for students to collaborate on design projects in real time using multi-user interaction with the design model, simulating a professional design scenario better than any design education assignment to date.

These studies offer a baseline for exploring the possibilities of spatial computing in learning today and provide a foundation for the promise of spatial computing in the realm of design education. It is essential for learning environments, specifically design education, to adapt as technology evolves, so that students can develop the necessary competencies to inhabit increasingly spatialized virtual worlds. Collectively, these studies highlight the need for ongoing research and empirical studies to explore the impact of, and to optimise the adoption of, spatial computing tools in design education.

III. Supporting Theory and Advantages of Spatial Computing in Design Education

Integrating spatial computing tools, such as the Apple Vision Pro and Nomad Sculpt, into the design curricula corresponds to Experiential Learning Theory (ELT) principles, which claim that learning is best acquired through active, experiential engagement. The founder of ELT, David Kolb, described the learning cycle as a spiral, covering concrete experience, reflective observation, abstract conceptualization, and active experimentation [12], [13]. By integrating spatial computing tools into chair design projects, students have a Concrete Experience with manipulating and interacting with 3D models that lends itself to constant Reflective Observation, specifically regarding how they respond to spatial structures and design principles applicable to learning. Abstract Conceptualisation of these principles – acquired from formal design education – is experienced through their application, and the Active Experimentation afforded by the immediacy and dexterity of spatial computing tools enables real-time interaction between students and digital objects, intelligent materials, and augmented reality. Designs can be iteratively tested and modified through rapid prototyping. This envisions a learning environment where the intellect is intertwined with the sensorial and where action can meet ideas through sensory-based creativity. This takes place in an environment that is different from traditional simulation or immersion, as well as lifelike; rather, it is designerly experiential learning that is less tangible but complex, adaptive, and dynamic. By using spatial computing tools, students will be prepared for these new demands of studio learning.

Spatial computing technologies, such as the Apple Vision Pro and Nomad Sculpt, offer distinct pedagogical advantages within the context of design education. Firstly, the ability to interact with three-dimensional models in real-time within a mixed-reality environment affords students a heightened level of visualization and immersion. This translates to a deeper understanding of intricate spatial relationships and design complexities, a crucial aspect of effective design education, particularly in fields demanding strong visual-spatial abilities [14], [15].

Furthermore, spatial computing fosters increased student engagement and facilitates collaborative opportunities. The inherent intuitive and hands-on nature of these technologies enhances engagement, rendering the design process more interactive and stimulating [16], [17]. Moreover, their real-time collaborative features enable geographically dispersed students to work seamlessly on projects. Several studies have proven this promotes teamwork, peer-to-peer learning, and contributes to a more dynamic educational environment [18]–[20].

Finally, a significant advantage lies in spatial computing's ability to streamline the prototyping process. The capacity to manipulate designs and instantly visualize results provides a rapid feedback loop [21], [22]. This encourages experimentation and exploration, ultimately accelerating the learning process. Students gain a swift understanding of the implications of their design choices, further enhancing their learning experience.

These advantages highlight the potential of spatial computing to enrich design education. By fostering stimulating learning environments, promoting deeper understanding, and better equipping students for real-world design challenges, these technologies hold significant promise within the field.

IV. User Study

A. Participants

The study involved 16 students who were divided into two groups of eight. Each group had to produce two chair designs within a period of two hours.

B. Materials and Methods

Participants randomly received an experimental group (two Apple Vision Pros) or a control group (two iPads). In both cases, participants each worked on the Nomad Sculpt app for the design tasks. All equipments were pre-installed the Nomad Sculpt application required for this experiment. Team members are free to rotate between executing the design on the app, group discussions and judging design elements, which could include mass, support, openings, shape of expression, technical articulation, conversation, structure, sustainability, form and fulfilment, in accordance with predefined judging criterion.

C. Procedure

The overall procedure of this innovative practice could be break down into two sessions: tutorial session and design session. All participants were introduced to Nomad Sculpt through a two-hour presentation before working on the designated design task as shown in Fig.1. This presentation provided a structured channel through which all participants gained a baseline level of knowledge. Crucially, the presentation did not include any live demonstrations, and participants were instead required to rely on the theoretical knowledge gained during the presentation when engaging with the practical aspects of the software during their team activities that followed. In addition to modelling a typical sequence for teaching new software tools, this arrangement provides a controlled environment in which to probe the effects of exposing learners primarily to written documentation and virtual or textual instructional aids.

The design session was structured to foster a dynamic exchange of ideas and responsibilities among team members, simulating a professional collaborative design environment. This approach was intended to maximize the creative and functional aspects of the chair designs. Teams are free to allocate responsibilities and roles for the design task.

All participants were given a questionnaire based on UTAUT(The unified theory of acceptance and use of technology) [23] regarding the Nomad Sculpt software used in the experiment. And those participants who were assign to the VisionPro group were given another questionnaire regarding the hardware.

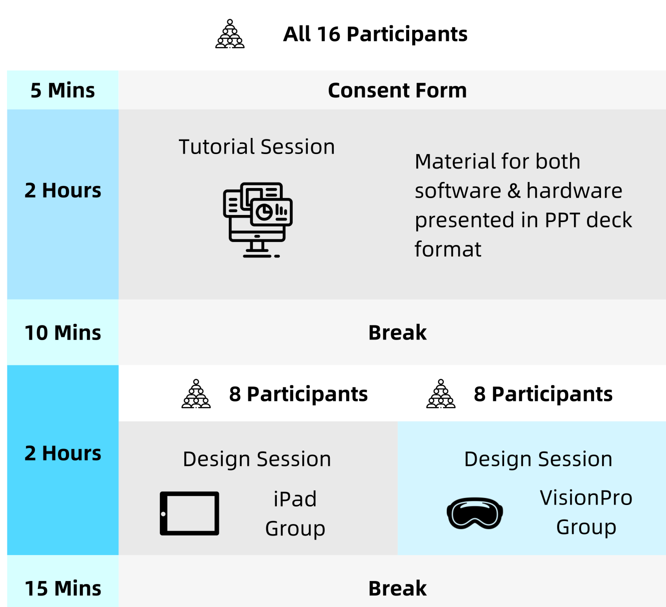

Fig. 1. Procedure of the Innovative Practice

D. Evaluation

Those resulting designs were then evaluated by a panel of five design experts, each with at least eight years of industrial design experience. The experts evaluated the quality of the designs using 10 criteria: mass, support, openings, shape expression, technical articulation, conversation, structure, sustainability, form and fulfilment. This judging standard has been proven by several studies regarding design and architecture researches [24], [25].

This user study investigates the influence of traditional versus advanced spatial computing tools on design outputs within an educational context. Comparatively analysing the creative end results and participatory process under different technological conditions, the study aims to offer insights on how to effectively integrate these tools into the industrial design education system.

TABLE I
UTAUT QUESTIONNAIRE FOR ALL PARTICIPANTS

Category	Questions
Performance Expectancy	1. How do you perceive the Apple Vision Pro will enhance your design process or learning experience?[a] 2. To what extent do you believe the Apple Vision Pro will enable you to complete tasks more quickly? 3. How significantly do you think the Apple Vision Pro will improve the quality of your designs or projects?
Effort Expectancy	1. How easy do you think it is to use the Apple Vision Pro? 2. Do you feel comfortable learning to use the Apple Vision Pro?
Social Influence	1. How do you think others' views on the Apple Vision Pro influence your willingness to use it? 2. To what extent does your network encourage using the Apple Vision Pro?
Facilitating Conditions	1. Are the necessary resources available to use the Apple Vision Pro effectively? 2. Is there adequate support available for using the Apple Vision Pro?

V. RESULT

The results will be explored qualitatively and quantitatively to evaluate deeply whether this innovative educational practice is making a real difference by using a mixed-methods approach. The analysis will enrich a better understanding of the pedagogical possibilities and practical problems of using immersive virtual reality child avatars in language learning. It will also investigate theoretically the implications of the findings for educational technology studies.

A. Qualitative Results

1) Participants Analysis: The total of 16 subjects, from the ages of 18-22, was chosen deliberately to ensure full representation of students across the spectrum of design education, but deliberately without anyone majoring in industrial design – a decision made to avoid varying technical skills and levels of experience, which tend to skew more towards specialisation than in other design disciplines. The fields of study represented among the participants could be demonstrated in Fig.3.

This multidisciplinary cohort was brought together to provide a broad view on the utility and efficacy of spatial computing tools across spatial domains of design practice. Their diverse academic specializations allowed for an understanding of how spatial computing tools enhance or hinder the affordances of creativity and the practice of making in disciplines that are more or less spatially defined than industrial design. This diversity ensured that the findings would generalize across various designs, avoiding an over-specialization to only technically oriented or highly specialized design fields while providing broad insights about the educational effects of spatial computing technologies. It also reveals the wide-ranging applicability of spatial computing tools to improve educational outcomes across the design-education continuum.

2) Feedback regarding VisionPro Hardware:

- Performance Expectancy: Participants gave positive feedback about the performance of the VisionPro Hardware, specifically commenting on high-resolution display and real-time processing, key factors that contribute to making the system reliable and improving the design experience. In particular, participants mentioned the capacity of the hardware to handle complex 3D modelling tasks without significant delays, thus supporting in a reliable manner their creative and technical needs in design projects.
- Social Influence: Other feedback indicated that participants were influenced positively by the reputation of VisionPro Hardware in professional circles, and by the fact that the hardware was becoming increasingly popular. They were motivated to learn how to use it since they understood that it is a cutting-edge tool in the field, which added a professional vibe (and an element of excitement) to their learning experience. Other feedback indicated that participants were influenced positively by the reputation of VisionPro Hardware in professional circles, and by the fact that the hardware was becoming increasingly popular. They were motivated to learn how to use it since they understood that it is a cutting-edge tool in the field, which added a professional vibe (and an element of excitement) to their learning experience.
- Facilitating Conditions: To ensure a facilitating condition for its use, participants emphasised the significance of having accessible support and integration with other systems. Participants noted the ease of setting up and integration of VisionPro into their existing workflows as a pivotal enabler for its use in an educational or professional environment.
- Effort Expectancy: We asked the participants to rate all aspects of the technology in relation to the above descriptions. They rated the hardware as easy to use primarily because its design and interface were ergonomic (fit comfortably to the body) and human-centred. Although some aspects of the hardware required some learning (e.g., the advanced features), there was a perception

	Mass	Support	Openings	Shape Expression	Technical Articulation	Conversation	Structure	Sustainability	Form	Fulfillment	
	2	4.8	2.2	4.2	2.2	3.8	4	1	2.8	2.8	2.98
	3.6	2	2.8	4.4	3.2	4.4	2.4	1.8	3.2	3	3.08
	3.2	4	3	2.6	3.2	2.2	2.2	4.4	2.4	2.8	3.06
	3	2.8	2	1.8	2.2	3.4	3.4	3.2	3	3.6	2.8

Fig. 2. Evaluation for Four Chair Designs

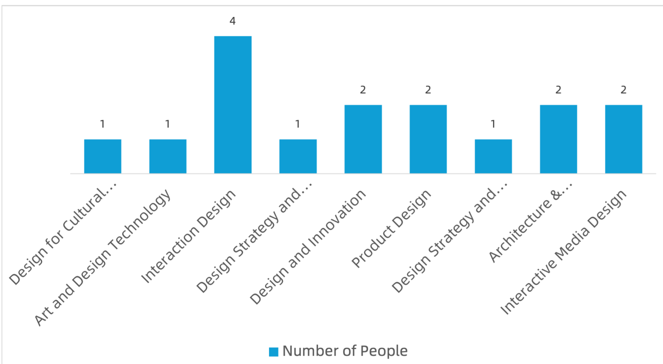

Fig. 3. Field of Study Breakdown for All Participants

that the overall effort necessary for learning how to use the hardware was not excessive. This is because easily accessible training materials and customer support was available to the user, which reduced the perceived effort expectancy.

3) Feedback regarding Nomad Sculpt Software: The feedback for Nomad Sculpt software is collected based on the questionnaire as shown in Table I.

- Performance Expectancy: Participants noted high satisfaction with Nomad Sculpt's success, including its easy-to-use and straightforward interface and extensive feature set that offered enough flexibility for a seamless design process. Some commented that the software worked as expected (some even better) and allowed for creative design exploration, contributing to their project's success. Feedback indicated that the Nomad Sculpt software allowed for quick rendering and visualization of complex design designs, which maximized creativity, productivity, and efficiency during the design sessions.
- Social Influence: The participants' comments suggested that social influence was a factor in their perception and utilization of the Nomad Sculpt software. A number of them mentioned that the positive experiences that colleagues shared with them and the recommendations from those who had tried it had a significant influence on their willingness to engage with the software. I also received many comments about the community and shared resources and how they helped the participants feel more comfortable using and learning more about the software independently.
- Facilitating Conditions: Participants appreciated being afforded supportive conditions, like access to tutorials and customer support, which flattened the learning curve of using Nomad Sculpt. Some participants also noted that their ability to exploit the software to its full potential would have been further improved if they had more access to advanced training. Support materials and a responsive user community were seen as essential enablers for using the software in the context of a design-education environment. Effort Expectancy: The results of the questions about effort expectancy were positive overall – participants commented that the interface on Nomad Sculpt is intuitive and easy to use. In particular, they commended its simple layout and the responsiveness of the controls, available right from the start, which 'reduced the effort that a participant would need to put in to accomplish a specific result. Some remarks indicated that prior experience with similar sculpting programs was helpful, suggesting that – even though participants had previously sculpted using AltspaceVR – there might still be a learning curve associated with Nomad Sculpt for true novices. These comments highlight how vital user experience design is to the willingness and ability to adopt and apply new tools in educational contexts.

These qualitative insights also imply that even though Nomad Sculpt is rated highly for technical effectiveness, training, and resources could make facilitating conditions more conducive to learning and use.

B. Quantitative Results

The major quantitative data for this innovation practice is the ratings and evaluations for the design results for the four chairs designed by both teams: VisionPro group(VPG) and iPad group(IPG).

1) Data Analysis across Four Designs: Overall, the evaluation is done according to 10 parameters: mass, support, openings, shape expression, technical articulation, conversation, structure, sustainability, form, and fulfillment. For every criterion, the chairs are rated from 1 to 5, with 5 indicating the best score in every criterion and the total performed across the parameters results in an average score between the chairs. We discuss the performance of the criteria and the implication as follows.

- Mass and Support:
  Note that the second design by VPG got 4.8 in Support but only 2 in Mass, indicating an excellent structure that lacks material mass, perhaps affecting stability.
  The third chair designed by IPG combined the highest level of Mass (3.2) with the next-to-highest level of Support (4), and was visually the most stable, the most distributed of the three.
- Shape Expression and Technical Articulation:
  While chair design one and two were able to express shape more effectively, scoring 4.2 and 4.4 each – higher than chairs three and four (3.6 and 4). This suggests their designs were more aesthetically pleasing or novel. Design two and three (3.2) were the chairs with highest correspondences between Technical Articulation and Shape Expression. For these two chairs, as for chair one, their higher Technical Articulation correspondences were also related to higher Shape Expression, a result which would suggest that a particularly good aesthetic design was also highly technically executed.
- Sustainability:
  Fourth chair design scored highest in dimension Sustainability (4.4), and probably the product is made from more sustainable material or by more sustainable production process, which is also the only difference between fourth chair design and the first design (1).

The overall scores seems to cluster together in the middle of the set, with second chair design getting top overall score of 3.08 and fourth chair design getting the lowest of 2.8. The second chair design may have scored highest overall due to the excellent scores it received for Support, Shape Expression, and Conversation.

2) Comparison with Two Groups: The data for both groups were also calculated and could be demonstrated in Fig.4. A look into the graph suggests that the two groups perform more or less equally across several parameters, with some variation that may point out specific areas of focus and improvement for each separately. We can see that VPG performs significantly better in terms of Shape Expression, Conversation, and Structure, which indicates that this group adepts better at design challenges, design complexity, and aesthetics while being better at communicating their ideas and being more sturdy and cohesive. Conversely, IPG performs significantly better then VPG in terms of Support and Sustainability, which may point out a more robust approach in terms of design philosophy where robustness and environmental aspects are highly emphasised. On the other hand, a close competition in terms of Mass, Technical Articulation, Form and Fulfillment, suggests a more equal capability between the two groups while nevertheless pointing out specific areas where the two groups optimised their design strategy separately to excel or at least stay at the industry standard. Overall, this comparison highlights how the competitive scenario in design and innovation is ruthless and leaves no space for flaws. It also pinpoints areas for further development and focuses on future projects for the two groups separately.

These results suggest that, in the context of design education, balancing psychological and experiential, cognitive and practical, and sustainable aspects of design is essential to meet aesthetic and practical demands. It is also supported by the data that initiative and effort are highly associated with sustainable design.

This rigorous assessment of chairs using multiple criteria is also an illustration of the complexity of design judgement: of how it is challenging to make any one element or attribute of design excellent but also how it is possible to keep oneself focused on judging excellence within a designated zone as long as it's specific, whether it is about design for sustainability, or technical articulation or aesthetics. Armed with this knowledge, future design projects and curricula could place greater emphasis on the systems-like nature of design that involves function, form and sustainability.

VI. Discussion

A. Comparison with Existing Studies

These results highlight the potential of spatial computing technologies, including the Apple Vision Pro and the Nomad Sculpt, to aid learning in design education. This is in line with previous studies that have shown how immersive technologies could provide a deeper understanding of complex spatial relationships and facilitate creative problem-solving. For example, studies on design education have shown that immersive environments could lead to a substantial improvement in spatial reasoning skills.

However, where ours differs from the previous literature is in providing a substantive quantitative demonstration of these effects in a laboratory setting, so providing a measure of empirical, evidence-based justification for integrating these technologies into design curriculum. Our studies differed from earlier studies in that we used both subjective and objective measures of user experience, in contrast to earlier studies, where, although the outcomes were subjected to objective measures, the subjective experience of the technology was predominantly assessed through user surveys.

B. Implications for Practice

The real-world implications of our findings are vast for design education, leading us to believe that spatial computing could offer a powerful new tool in the curriculum. Building on our findings, we offer the following recommendations for education:

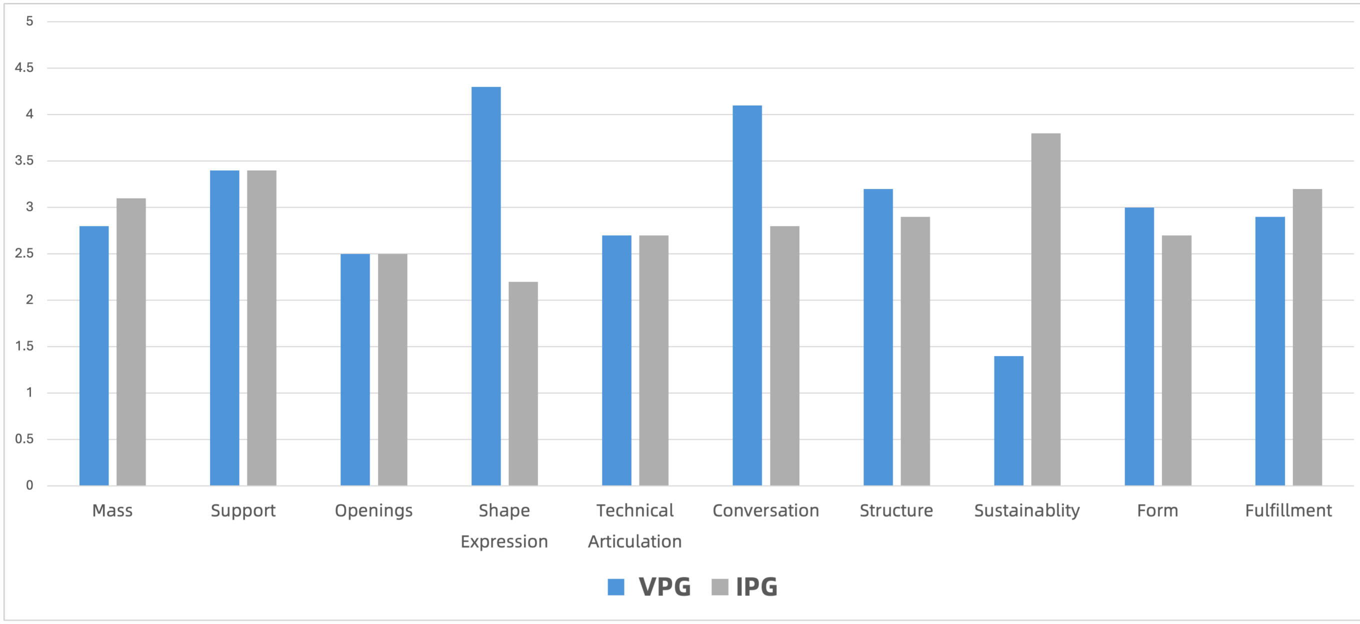

Fig. 4. VisionPro Group(VPG) demonstrated stronger design performance in "Shape Expression", "Conversation" and "Structure".

- Integration into Curriculum:
  Institutions should integrate spatial computing tools into design curriculum as a matter of course, and use them in introductory design courses where students can develop a strong sense of 3D literacy as a basis for spatial expression.
- Collaborative Projects:
  Thanks to the increased collaborative affordances of spatial computing tools we discovered, educators could develop more team projects that use those technologies. This approach could more closely replicate professional design environments, preparing students for the real world.
- Training and Support:
  It will be necessary to overcome a learning curve to make use of new technologies, so training sessions should be made available for students and instructors. Depending on the nature of the technology, technical support must be in place to allow smooth integration in teaching and learning activities.
- Longitudinal Studies:
  Most importantly, longitudinal studies should be established to follow students who use these tools throughout their education to evaluate long-term effects on their design thinking and problem-solving skills.

VII. Limitations

Though this is a helpful study on an innovation practice, some critical limitations exist. The small sample size may limit the ability of this study to be generalizable to broader populations. Another limitation is that the study took place in a controlled environment, which may not represent all the variables in a typical classroom environment. Moreover, since only two types of spatial computing tools were used, there may be some tool-specific biases that would limit the ability to generalize this study's findings to other technologies or platforms. Also, the hardware used in this study, Apple Vision Pro, offers limited accessibility and flexibility when it comes to sharing and working with one device. Future studies should aim to mitigate these limitations by including more extensive and diverse populations with multiple types of spatial computing tools across different design fields.

VIII. Conclusion

Among the deliverables of both design teams was their use of design tools with or without spatial computing: to identify and unpack the pedagogic affordance of creating a chair design project Nomad Sculpt and to assess the extent to which immersive technology can improve creativity, engagement, and the ability to apprehend spatial relations. The designers' outcomes increased significantly when using the new technology. We hypothesized that spatial computing could change design education – precisely what we found. This study not only demonstrates the potential to augment learning outcomes in students with immersive technologies but also opens up the possibility that, over time, education itself will need to be rethought and understood with a new lens if we want to benefit fully from spatial computing. Based on the findings, we believe it is essential to embed spatial computing tools into design education intentionally. This requires networked infrastructure to support it and training for teachers and students to use new technologies as they come online. The two together indicate that further research is needed to understand the full spectrum of applications for spatial computing in education and the long-term implications of using these technologies for learning engagement and creativity. The research is also recommended to be extended to an even broader set of tools and contexts for learning to understand better the opportunities and challenges spatial computing offers to learning. Overall, this study shows that immersive technologies can add dimensionality and tools to the classroom, re-energizing the design curriculum. As with technological advancements, institutional practices must adapt to a changing professional landscape.

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