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Exploring the usability and creativity enhancement of augmented reality in additive manufacturing-based product design

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ABSTRACT

Augmented Reality (AR), a technology that overlays digital content onto the physical environment, holds promise for enhancing creativity and usability in product design education. However, despite the advantages of Additive Manufacturing (AM) in enabling complex and customizable designs, designers often struggle to grasp its abstract principles. Grounded in theories of immersive learning and multimodal visualization, this study investigates whether integrating AR visualization can facilitate better understanding and stimulate creativity in AM education. A controlled experiment was conducted with 34 master's students in product design, randomly assigned to either an AR-based learning group or a traditional card-based learning group. Participants engaged with AM principles through either an interactive AR application featuring manipulable 3D cube models or static information cards. Usability perceptions and creativity of design outputs were assessed respectively through structured questionnaires and expert evaluations by five domain specialists. Mann–Whitney U tests, appropriate for non-normally distributed data, revealed that the AR group reported significantly higher usability ratings and produced more original design outcomes compared to the card-based group. These findings demonstrate that AR-based educational tools can directly improve the usability and creative engagement of students in learning AM principles. This study contributes to advancing the understanding of how immersive technologies can be effectively integrated into design education to foster both practical skills and innovative thinking.

1. Introduction

Additive Manufacturing (AM), which fabricates objects directly from digital 3D models through a layer-by-layer process (Gibson et al., 2010), has transformed design and production in sectors such as aerospace, medical, and automotive industries (Bai et al., 2020; Culmone et al., 2019; Madhavadas et al., 2022; Wiese et al., 2020). With advantages such as customization, material efficiency, and reduced lead times, AM is increasingly adopted beyond prototyping to the production of final-use parts. Despite its growing industrial application, design students and designers often have the challenge to understand and apply AM effectively due to its technical complexity and the abstract nature of digital fabrication principles (Mathur et al., 2024).

To address this gap, educational strategies must go beyond textual descriptions and static visuals. Augmented Reality (AR), which overlays virtual content onto the physical world (Azuma, n.d.), presents a compelling opportunity. By enabling immersive, interactive experiences

in real-world contexts, AR has shown promising results in enhancing user engagement and understanding in domains such as education (Bursali & Yilmaz, 2019; Campo et al., 2023; Chen, 2020; O'Connor & Mahony, 2023), business (Barta et al., 2023) and industry (Wang et al., 2022).

Yet, few studies have explored how AR can be effectively leveraged to support designers' understanding of AM and foster creativity in design tasks. Furthermore, limited empirical evidence exists regarding how AR-based tools influence design outcomes and learning in AM-related tasks.

This study aimed to assess whether the use of AR could foster designers' creativity and improve their understanding of AM. The AR application features 14 cube models. Each cube highlight a distinct aspect of AM (Lang et al., 2021). The application enables designers to explore and interact with these models within an AR environment. By interacting with these models in an AR environment, designers gain deeper insights into the complexities and advantages of AM technology.

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The remainder of this paper is structured as follows. Section 2 reviews the state of the art in the relevant fields. Section 3 outlines the research methodology, detailing the design of the AR application and the framework of the controlled experiment. Section 4 presents the experimental results and provides a comprehensive discussion. Finally, Section 5 offers conclusions and recommendations for future research.

2. Literature review

2.1. AM technology

AM is an advanced industrial technology that provides innovative solutions to a wide range of manufacturing challenges (Ford & Minshall, 2019; Langridge et al., 2018). Its rapid growth has benefited from many advantages over traditional methods, including cost efficiency, reduced material waste, and a unique high degree of freedom that allows for creativity and innovation (Madhavadas et al., 2022). AM technology has been adopted by various industries such as aerospace (Blakey-Milner et al., 2021; Madhavadas et al., 2022), automotive (Alami et al., 2023; Wiese et al., 2020; Zhao et al., 2023), medical (Culmone et al., 2019; Dehghan-Manshadi et al., 2020), architecture (Al Rashid et al., 2020; Borg Costanzi et al., 2018; Salet et al., 2018), art and design (Hegab et al., 2023; Vaneker et al., 2020).

There are four types of complexity in AM: geometric, hierarchical, material, and functional (Gibson et al., 2010).

One of the main advantages of AM in product design is its ability to generate complex geometric shapes in a single operation, completely different from traditional reduced-material manufacturing. AM can make hollow and complex forms without having to divide them into multiple components. Therefore, producing with AM reduces the number of parts and the need for assembly operations. At the same time, the production of such a complex geometry does not lead to increased costs (Kim et al., 2024).

Hierarchical complexity makes it possible to build structures with many levels of detail, from the microscopic to the macroscopic scale. This allows the integration of complex internal features and lightweight design while maintaining mechanical performance. One of the most exciting aspects is its ability to produce lighter and more robust components that mimic natural designs, such as bone or cell structure (Chen et al., 2024; Yao et al., 2024).

Material complexity means that AM can use multiple materials to produce components with different properties in a single manufacturing process. This includes combining different metals, polymers, or composites to achieve specific properties (Ge et al., 2024). AM is able to precisely position and integrate these materials so that components are not only optimized for performance.

Functional complexity is the ability to produce parts that integrate multiple functions within a single structure. This can include directly embedding sensors, electronics, or other active elements into the printed parts.

The following sections provide illustrative examples of each complexity type, demonstrating how AM enables innovative designs and processes that would be difficult to achieve with conventional manufacturing techniques. These examples show the role of AM in various fields, from aerospace engineering (Careri et al., 2023; Khan & Riccio, 2024; Madhavadas et al., 2022; Thohid Rayhan et al., 2024) to biomedical devices (Arif et al., 2023; Jiang et al., 2024; Kouhi et al., 2024; Mobarak et al., 2023; Tom et al., 2022) and energy storage solutions (Chen et al., 2021; Dhinesh et al., 2022; Divakaran et al., 2022).

Aerospace industry awards typically use complex components to improve aerodynamic performance, structural strength, and functional integration. AM provides the ability to manufacture these complex components with high precision. A key advantage of AM in aerospace applications is its ability to produce lightweight structures without compromising stability and strength (Madhavadas et al., 2022). AM achieves this through topology optimization, reducing the use of overall

materials, and maintaining structural integrity (Khan & Riccio, 2024). In addition, AM can select the appropriate material according to the specific requirements of aerospace components. AM allows the addition of graded materials or multiple combinations of materials to a single component to further optimize performance. This technique benefits high-cost materials such as titanium alloys and advanced composites (Careri et al., 2023). AM can also reduce the seams and joints required in traditional manufacturing processes, which are often potential structural weaknesses. Another significant advantage of AM is that it can integrate multiple functions into a lightweight structure. By reducing the number of components, AM not only simplifies the assembly process but also reduces the potential failure point, which plays a vital role in improving the reliability of the whole system.

In the medical field, AM can significantly improve implant design by taking advantage of multiple types of complexity. AM achieves geometric complexity by manufacturing patient-specific implants with complex geometries and hierarchical complexity by creating multiscale structures that optimize mechanical and biological performance; material complexity is achieved by integrating graded or multi-material combinations for specific properties. Meanwhile, AM supports functional complexity by directly combining functions such as drug delivery systems or embedded sensors into the implant structure. These demonstrate the potential of AM to improve implant fabrication, surpassing the limitations of conventional manufacturing techniques (Mobarak et al., 2023).

Recent studies have demonstrated that AM has been extensively employed in battery production due to its ability to fabricate intricate structures with precise control over the geometry and thickness of electrodes (Dhinesh et al., 2022). The technology allows for creating geometrically complex, hierarchically organized, and functionally optimized components that would be challenging or impossible to produce using conventional manufacturing methods. Moreover, AM facilitates the printing of electrolytes with enhanced structural stability, contributing to improved overall battery performance. AM does not need traditional assembly and packaging, so it integrates the battery directly into the device. Thus simplifying production and further increasing the functional complexity (Divakaran et al., 2022).

AM is used in product design not only because it can produce complex structures. It also provides flexibility in material selection and performs well in cost control. AM provides designers with freedom, significantly promoting product design innovation.

2.2. AR technology

AR is a technology that overlays digital information, such as images, sounds, or other data, onto the user's view of the real world in real-time, thereby augmenting their perception of the environment (Azuma, n.d.). This is achieved by integrating virtual elements with the physical environment, typically through smartphones, tablets, or AR glasses. AR enables interactive experiences, enhances users' ability to interact with their environment, and it has a wide range of applications, including education (Bursali & Yilmaz, 2019; Campo et al., 2023; Chen, 2020; Chiang et al., 2022; O'Connor & Mahony, 2023; Thees, 2020), business (Barta et al., 2023; McLean, 2019; Nugroho & Wang, 2023; Oyman et al., 2022) and industry (de Souza Cardoso et al., 2020; Eswaran & Raju Bahubalendruni, 2023; Fan et al., 2024; Hanson et al., 2017; Mompeu et al., 2024; Wang et al., 2022).

AR has demonstrated a profound impact on education (Al-Ansi et al., 2023; Hari Rajan et al., 2025; He et al., 2025; Sahin & Yilmaz, 2020). Some research indicate that AR significantly enhances learning results by overcoming the limitations of traditional educational tools (Buchner & Kerres, 2023; H.-Y. Chang, Binali, et al., 2022; Koparan et al., 2023). Compared to traditional methods, AR can offer a more interactive learning experience. Therefore, AR can increase educational effectiveness and student motivation (Rebello et al., 2024). A study showed that the students who used AR performed well in comprehension tests and

retained information better over time. The AR could enhance students' reading comprehension (Bursali & Yilmaz, 2019; Ou Yang et al., 2023). Student feedback indicates that AR makes learning more attractive and enjoyable, demonstrating its potential for educational applications. In another study, AR learning activities were evaluated for their effects on 9th graders' understanding of chemistry. The study found that the AR group performed better than the non-AR group in immediate and delayed tests. The students in the AR group also showed good memory ability of chemical concepts and expressed higher satisfaction with the AR learning approach. This research shows the potential of AR to increase student engagement in science education (Chen, 2020). Additionally, a study applied AR to a physics laboratory experiment on heat conduction, using AR glasses to replace traditional displays with virtual representations overlaid on real objects (Thees, 2020). This AR application significantly reduced extraneous cognitive load compared to traditional data collection methods. These findings show the potential of AR to enhance cognitive efficiency.

AR has become an essential tool in modern business, offering numerous advantages that enhance consumer experience and company performance (Walentek & Ziora, 2023). In retail, some AR applications provide interactive and immersive experiences, allowing customers to virtually try products before purchasing. It can significantly improve engagement and satisfaction (McLean, 2019). Furthermore, AR can reduce cognitive dissonance, increase purchase intentions and willingness to pay, and reduce return rate (Barta et al., 2023). AR's ability to combine digital and real environment experiences fosters personalized experiences that increase customer loyalty and long-term brand engagement. In digital marketing, AR-supported mobile applications can provide consumers with functional advantages such as informativeness, ease of use, and enjoyment (Oyman et al., 2022). In addition, AR helps businesses minimize the display of physical products and achieve real-time virtual display in e-commerce to help reduce operating costs, which is particularly important in industries such as fashion and beauty (Nugroho & Wang, 2023).

AR also has the growing impact in industrial field, particularly for training, assembly, and improving worker and improving worker well-being. AR-based instruction has been shown to enhance accuracy and reduce learning time in manual assembly and repair tasks (Wang et al., 2022). In metal AM, AR integrated with advanced vision-language models facilitates immersive training for non-experts (Fan et al., 2024). Additionally, the use of AR smart glasses in warehouse order picking has improved task efficiency and reduced physical strain (Windhausen et al., 2024).

AR has the impact on fostering creativity across fields such as product design, customer engagement, and artistic expression. Studies show that AR's ability to merge virtual and real-world environments facilitates immersive, interactive experiences, driving creative play and ideation (Zünd et al., 2015). This is especially evident in co-creative product and packaging design, where AR enables designers to prototype and refine concepts in real time, fostering collaborative creativity (Cascini et al., 2020). Additionally, AR enhances consumer engagement by creating immersive "playground effects" that inspire customers to interact creatively with brand content (Jessen et al., 2020). Moreover, in artistic expression, AR broadens the creative palette by blending digital and physical media, enabling artists to craft multisensory experiences (Wang et al., 2024). Collectively, these applications highlight AR's potential to advance creativity in educational, professional, and commercial fields.

In conclusion, the integration of AR into education and training has proven to be highly effective in delivering immersive, interactive, and enriched learning experiences across diverse fields. The ability of AR to overlay virtual content onto physical environments, allowing learners to engage with complex concepts in real time, makes it particularly valuable for technical and applied domains. Given these strengths, AR's ability to visualize AM models offers a valuable tool for designers to better understand the properties and capabilities of AM technologies. By

providing real-time, interactive representations of complex AM models, AR allows designers to explore material behaviors, geometrical constraints, and manufacturing techniques in a more intuitive and accessible manner. This approach enhances their comprehension of AM characteristics, leading to more informed and innovative design decisions.

2.3. Creativity

Creativity is often defined as the ability to generate novel and appropriate ideas, products, or solutions within a specific context. In design, creativity not only implies originality but also considers relevance to user needs and situational demands (Gong et al., 2024; Shute & Rahimi, 2021). Novelty refers to the uniqueness and innovation of the design, while appropriateness measures the practical value and functionality of the idea within its context (Brigham Young University et al., 2006; T.-S. Chang, Binali, et al., 2022).

Assessing creativity, particularly in design, presents challenges due to its inherently subjective nature (Bonnardel, 2000; Jordanous, 2012). A range of evaluation methods has emerged, generally categorized as subjective or objective. Among these, expert evaluation is prominent, especially for assessing creative outcomes in design fields that require deep domain-specific knowledge (Sarkar & Chakrabarti, 2011). Experts utilize established standards and personal experience to assess creative outputs, with consensus among multiple experts often serving as an indicator of a work's creative value. While effective, expert evaluations can be influenced by personal biases, lack of standardized criteria, and subjective interpretation.

In contrast, objective methods employ structured, quantifiable frameworks, algorithms, and scoring systems to assess creativity in a more consistent manner (Jordanous, 2012). Although these methods can reduce subjectivity, they require significant resources and may fail to capture unique or domain-specific aspects of creativity.

Combining expert evaluations with objective frameworks offers a balanced approach to creativity assessment (Gong et al., 2024). This hybrid approach can leverage the reliability of objective systems while incorporating the nuanced judgment of experienced professionals, providing a more holistic framework that addresses the limitations of each individual method. This combined strategy is especially beneficial in complex or innovative design contexts, where capturing both technical consistency and creative uniqueness is essential.

2.4. Integration AM with AR

AR has demonstrated significant advantages in the field of AM, particularly in enhancing training and operational efficiency (Bozzi et al., 2023). AR's integration into AM training systems offers an immersive and interactive learning environment, addressing the limitations of traditional methods. By overlaying digital information onto the physical environment, AR enables real-time visualization and interaction with complex manufacturing processes.

Fan et al. propose a novel training method for metal AM that provides non-experts with an immersive training experience by integrating advanced visual language models and AR technology (Fan et al., 2024). This study addresses in AM skill training, particularly for users without a professional background in the field. By embedding a visual language model into an AR system, this approach dynamically identifies and interprets the complex steps of metal AM processes and provides real-time visual guidance, greatly simplifying the understanding and acquisition of complex information. The methods introduced by Fan et al. not only enhance users' awareness of the manufacturing processes but also highlight the potential of AR technology in technical training for non-experts, providing valuable theoretical and practical insights for smart training in manufacturing. Compared with traditional training methods, this approach significantly improves training efficiency and operational accuracy, especially in fast-paced, high-precision

manufacturing environments. Fan et al.'s findings demonstrate new application pathways for visual language models in manufacturing training and further expand the prospects of AR in intelligent manufacturing. This approach simplifies complex concepts and improves understanding of operational procedures. AR systems also facilitate real-time feedback and visualization of manufacturing conditions, which helps trainees to grasp intricate details more effectively.

The implementation of AR in AM training systems has shown to improve recognition accuracy and operational efficiency. Overall, AR represents a transformative technology in AM, offering substantial improvements in training methodologies and operational insights. Its ability to create interactive, real-time simulations and provide detailed guidance underscores its potential to advance the field of smart manufacturing (Tadeja et al., 2023). However, although AR has proven effective in both training and business environments, there are still significant gaps in its application in the early design phase of AM processes. At present, AR's application mainly focuses on the post-design and training stage, and there is little research on how to integrate AM into the early design stage with AR technology (Cui et al., 2024). Despite the rapid growth of AM within Industry 4.0 (Elhazmiri et al., 2022), its widespread adoption faces several hurdles, most importantly a lack of expertise, especially among designers.

Currently, designers face challenges in grasping the complexities of AM, which can limit their ability to fully leverage its potential for innovative solutions (Ostrander et al., 2020; Stavropoulos et al., 2023). Integrating AR into the design stage offers an interactive, real-time simulation environment, allowing designers to explore AM knowledge and make more informed design decisions. We hypothesize that incorporating AR-based application into the early design process for AM can enhance designers' understanding of AM principles and techniques. This improved understanding is expected to foster more innovative and optimized design outcomes by reducing knowledge barriers and enhancing creativity.

2.5. Research purpose and questions

Although extensive research has explored the capabilities of AM and the benefits of AR in education and training, there is a clear gap in applying AR to support designers' comprehension of AM principles and capabilities at the initial design stage. Current studies mainly focus on post-design stages, leaving the integration of AR for enhancing designers' understanding and creativity in conceptual design underexplored. This study addresses this gap by investigating how AR-based interactive visualization of AM models can improve designers' comprehension of complex AM principles and foster more innovative design outcomes. The findings are expected to contribute both to the theory and practice of combining AR and AM in design, promoting more effective and creative product development. Based on the identified research gap, this study is guided by the following research questions:

- Could AR support designers' understanding of complex AM principles?
- To what extent does interacting with AR-based AM models influence design students' creativity compared to traditional representations (i.e., paper cards)?
- What advantages does the AR application offer over traditional representations in supporting students' conceptual design learning experience?

3. Research methodology

In this research, we adopt Design Science Research (DSR) to develop the AR application to display the 14 cube models that can present the potential of AM. DSR, as proposed by Hevner et al., emphasizes addressing practical problems while generating new knowledge through the design and evaluation of artifacts (Hevner et al., 2004). It comprises

key components including problem relevance, design as an artifact, design evaluation, research rigor, and clear communication of research contributions. Compared with other research approaches—such as experimental research, which primarily tests predefined hypotheses under controlled conditions, or action research, which focuses on participatory change processes—DSR is particularly well suited for studies involving the development of innovative technological tools. Its dual emphasis on artifact creation and evaluation enables researchers not only to produce functional solutions but also to derive generalizable insights about design processes and user engagement.

In this study, the AR application serves as a DSR artifact, specifically designed to tackle the interaction and visualization challenges associated with demonstrating AM models. Following DSR principles, our process involved iterative design cycles, where each cycle included designing, testing, and refining the AR application to ensure usability and enhanced user experience. Through multiple design iterations and validations, we aimed to optimize the AR tool's functionality to better support designers in understanding AM capabilities. This approach aligns with DSR's emphasis on iterative refinement to address user needs and advance practical knowledge in the field.

We also combined the advantages of the Agile Development Model (ADM) and Design Thinking (DT) to rapidly iterate the AR application's development. ADM allows us to respond flexibly to changes in the development process and improve system functionality through continuous user testing (Abrahamsson et al., 2002; Erickson et al., 2005). We progressively implemented and tested different functional modules, such as AR model presentation and user interface enhancements, through short iterations. At the end of each iteration, gathering user feedback enables us to quickly adapt the design and functionality to meet user needs. This approach not only ensures that the user experience of the application is optimized but also improves the development efficiency.

Moreover, the DT offers a user-centered innovation framework for our AR application, emphasizing a deep understanding of the user's needs and challenges. The development process involves stages such as empathy, definition, ideation, prototyping, and testing to ensure that the designed application effectively addresses user needs (Brown, 2008; Razzouk & Shute, 2012). The application aims to improve the experience of users and the sense of participation, ensuring the final application has strong performance in terms of attractiveness and practicality. As Fig. 1 shows, our development methodology integrates DSR, ADM and DT to support iterative AR application development.

3.1. AR application design

The AR application was developed following a user-centered design philosophy, combining DT and ADM to iteratively refine functionality based on designer feedback. This approach ensured that the application effectively addresses the challenges of presenting and interacting with AM cube models.

The 14 physical AM cubes (3 cm × 3 cm) effectively demonstrate AM potential but have limitations such as small size restricting detail observation and fixed material properties requiring costly remanufacturing (see Fig. 2). The AR application overcomes these constraints by enabling interactive visualization and material customization, enhancing designers' understanding and engagement.

Implemented with Unity and OpenXR, the application runs on the Android smartphone, providing an immersive environment for intuitive interaction with virtual models. Fig. 3 presents the 14 physical cubes alongside their corresponding 14 virtual counterparts. The physical cubes are displayed on the left, while the virtual cubes are shown on the right.

The application consists of three main modules, Model Presentation Module (Fig. 4), User Interaction Module (Fig. 5) and Associated Models Display Module (Fig. 6).

Throughout the development process, we adopted ADM to ensure

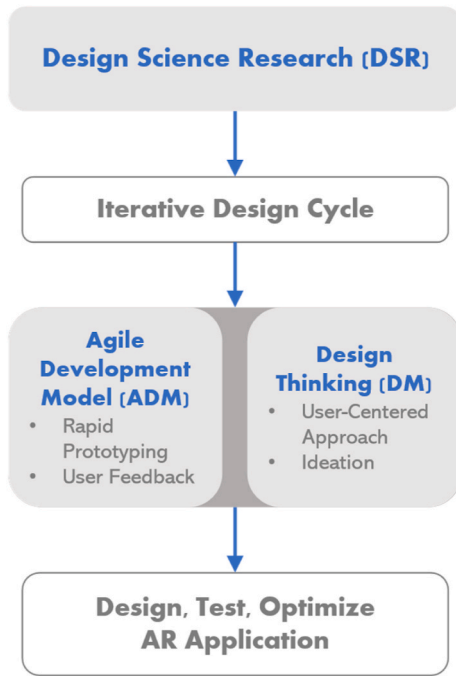


Fig. 1. Research methodology.

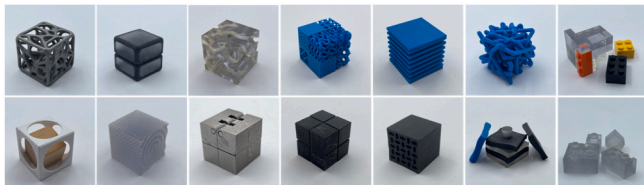


Fig. 2. The 14 AM cube models.

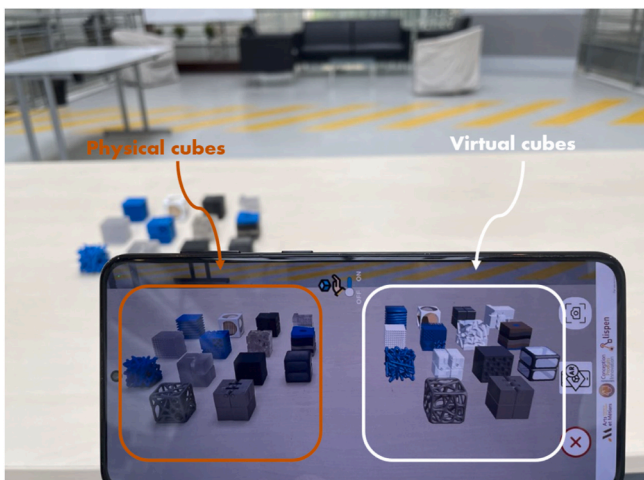


Fig. 3. 14 physical cubes and 14 virtual cubes.

iterative improvements based on user feedback. Following each development iteration, users feedback was collected regarding the application's functionality and overall experience, enabling continuous refinements in areas such as usability and feature responsiveness. The resulting AR application offers a significant advancement in the visualization and interaction with AM models, providing a level of flexibility not achievable with physical models.

3.2. Experimental setup

The experiment is designed to evaluate whether the AR application improves designers' understanding of AM and enhances creativity compared to traditional methods. A comparative experiment was conducted with two groups: Group A used printed cards containing information about cubes, while Group B used AR application to interact with 14 virtual AM cube models. Both the printed cards and the AR application present the same set of 14 cube models, ensuring consistency in the range of models provided to participants. While the cards include more detailed textual descriptions, the AR application emphasizes interactive 3D visualization.

After interacting with the cubes using their assigned method, both groups completed a design task, followed by a questionnaire. The design task aimed to assess their ability to apply AM knowledge in a product design context. Subsequently, the completed design sheets and questionnaire responses were evaluated to measure the participants' creativity and to compare the effectiveness of each learning method.

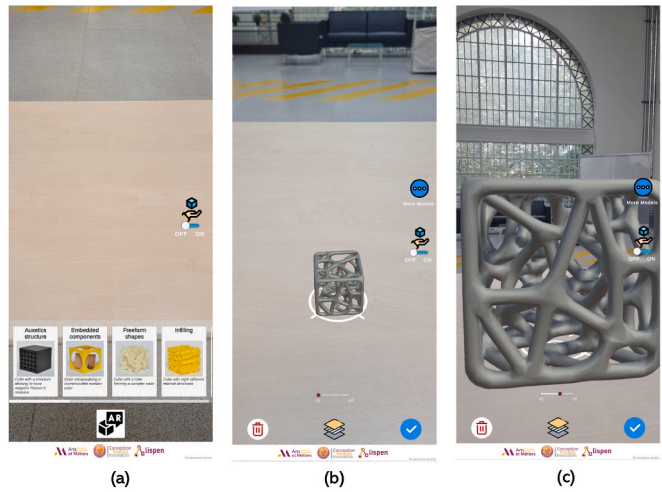
3.2.1. Participants

The study involved 34 engineering students (30 male, 4 female; age range 23–25) from ENSAM (École nationale supérieure d'Arts et Métiers), a leading French engineering institution with a strong focus on innovation and industrial design. All participants had foundational knowledge of AM through prior coursework, but none had substantial experience with AR applications. Participants were randomly assigned to 2 groups.

3.2.2. Experimental Procedure

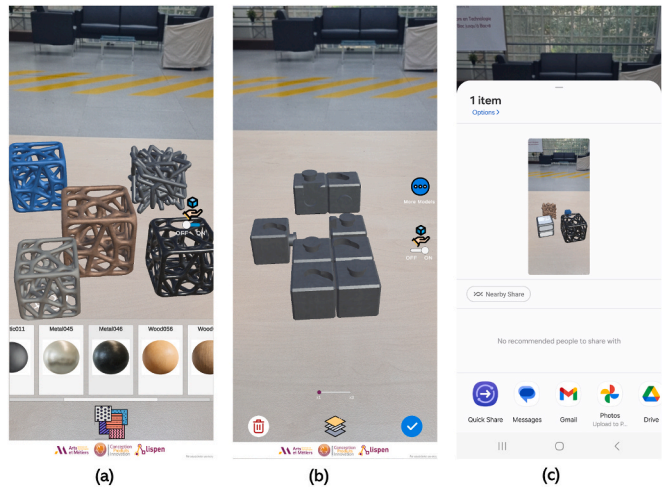
The design task required participants to conceptualize kitchen utensils using AM principles, producing hand-drawn sketches accompanied by textual descriptions. No additional tools were provided. The experiment consisted of 5 steps. All the experimental steps are illustrated in Fig. 7. All experimental steps, including task introduction and model exploration, were conducted within the groups. The AR group was provided with two smartphones to use the AR application, while the card group was provided with two sets of paper cards. During the initial 20-min exploration phase, each participant individually interacted with the AR application on the smartphones or read the cards. In the subsequent 60-min brainstorming phase, the AR application and cards remained available within the group, and each group member had the opportunity to operate the smartphones or explore the cards, allowing all members to continue interacting and collaboratively generating ideas. The final design outputs were produced at the group level, and participants were instructed to leverage AM principles as extensively as possible in their designs. The 60-min time frame for the design task was set based on standard durations commonly used in undergraduate product design courses to ensure a realistic and manageable workload. To ensure that participants had sufficient time to review the printed cards or learn how to use the AR application before the task, we conducted a pilot test with a group of volunteers prior to the formal experiment. The feedback from the pilot confirmed that the allocated time was adequate.

1. Group assignment: We divided participants into 2 groups. Group A received traditional printed cards containing AM cube information. While Group B used the AR application.
2. Introduction (10 min): Group A received printed cards containing information about each cube, with images and technical specifications. Group B was introduced to the AR application, including detailed instructions on how to interact with the virtual cube models, adjust their size, and explore different material properties. Both groups were briefed to ensure they understood how to effectively use their respective tools for the subsequent tasks.
3. Model Exploration (20 min): Control Group: Participants explored the 14 cube models using the printed cards to understand AM. AR



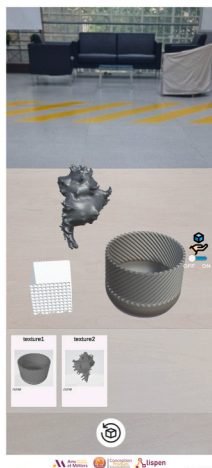
- (a) Users can browse cube models in a card-based interface with images and descriptions.
- (b) Selected model can be rotated, moved via touch interaction.
- (c) Selected model can be resized via touch interaction for detailed exploration beyond physical size limits.

Fig. 4. Model presentation module.



- (a) Users can dynamically change the cube's material and scale to simulate different appearances.
- (b) A step-by-step assembly guide supports structural understanding.
- (c) Screenshots can be captured at any stage for documentation.

Fig. 5. User interaction module.



Once a cube is selected, the user can view structurally related models by clicking the corresponding button.

Fig. 6. Associated models display module.

enhancing kitchen products utilizing principles of AM. This task encourages creative thinking and application of AM concepts in practical scenarios.

5. Questionnaire (10 min): Upon completion of the design task, participants were required to fill out a questionnaire.

3.3. Data collection and analysis

In this study, data from questionnaires and design sheets were used to evaluate the usability and impact on creativity of AR application and cards-based method. The Mann–Whitney *U* test was employed to compare differences between two conditions.

3.3.1. Usability questionnaire evaluation

To evaluate participants' experiences and perceptions, we employed an adapted questionnaire based on existing studies on AR and user experience. Most items, except those measuring Perceptions of AM, were adapted from Kowalczyk et al. (Kowalczyk et al., 2021). The Perceptions of AM items were adapted from Pham Van et al. (Pham Van et al., 2022) to capture participants' understanding and attitudes toward AM. All participants, including those in the AR and card groups, completed the questionnaire. For the AR group, items referred to the AR application; for the card group, the wording was adjusted to refer to the paper cards. All items were measured on a 7-point Likert scale (1 = strongly disagree,

- Group: Participants explored the 14 cubes via the AR application, manipulating model size, material, and viewing assembly processes.
4. Design Task (60 min): Participants were instructed to brainstorm and complete design sheets centered around the theme of designing or

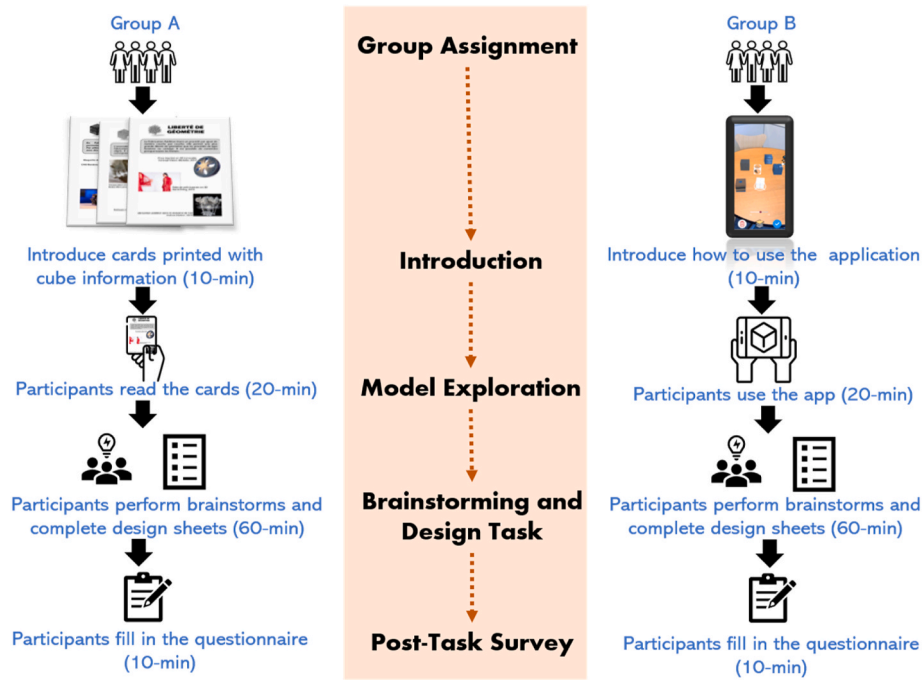


Fig. 7. Experimental procedure.

7 = strongly agree).

The questionnaire included the following dimensions:

Interactivity and System Quality: These dimensions assess users' perceived responsiveness, reliability, and control over the AR application and cards. Items focus on system performance, ease of use, and effectiveness in supporting task completion, which are crucial for user engagement and satisfaction.

Product Informativeness: Evaluated the extent to which the AR application or cards provided relevant information about the AM models, including geometry, structure, and material characteristics.

Reality Congruence and Immersion: This dimension assessed the perceived realism of the AM models (colors, shapes, and overall fidelity) and participants' engagement or attentional focus while interacting with them. For the AR group, it referred to the virtual models in the application; for the card group, it referred to the physical cards.

Cube Liking and Media Usefulness: Cube Liking measured participants' affective responses to the AM models, such as how pleasant or likable they found them. Media Usefulness assessed how effectively the AR application or card materials supported participants' learning and design tasks, including ease of acquiring information and improving design quality.

Reuse Intention: Assessed participants' willingness to use the AR application or card materials in future learning or design activities.

Perceptions of AM: This dimension captures participants' understanding and conceptual knowledge of AM after interacting with the AR application and cards.

3.3.2. Measurement of creativity

A wide range of creativity metrics have been employed in previous research to evaluate ideation and creative outputs (Brigham Young University et al., 2006; Shah et al., 2003; Verhaegen et al., 2013). These include metrics focusing on novelty, variety, quality, and quantity (Shah et al., 2003). However, our main concern was to assess the outcome of the creative process, specifically the final ideas generated by participants. So, in our study, quantity and variety were excluded. Given our focus on idea generation rather than tangible product outcomes, the product-oriented creativity assessments are less appropriate for us (Verhaegen et al., 2013). After reviewing various frameworks for

evaluating creativity, we adopted the approach outlined by Dean et al., focusing on two central dimensions: novelty and quality (Brigham Young University et al., 2006). Quality was further assessed based on workability, relevance, and specificity, ensuring a comprehensive evaluation of idea development (Gong et al., 2024). The specific content corresponding to each dimension is provided in Table 1.

Novelty measures the originality and innovation of the ideas and is further divided into two sub-dimensions: originality and paradigm relatedness.

Workability includes acceptability and implement ability, focusing on whether the idea can be feasibly applied within the constraints of the problem.

Relevance includes applicability and effectiveness, evaluating how well the idea aligns with the design objectives and its potential for successful implementation.

Finally, **specificity**, divided into completeness and implicational explicitness, measures the detail and clarity of the idea.

Five experts evaluated the design sheets using a standardized scoring rubric distributed and discussed prior to assessment. All raters had extensive expertise in product design and AM, with three being professors and two being PhD researchers. Following established guidelines (Brigham Young University et al., 2006), two different scale lengths were applied. Dimensions with fewer but clearly distinguishable performance levels were rated on a 3-point scale to maximize inter-rater agreement, whereas dimensions requiring finer differentiation were rated on a 4-point scale to capture more nuanced variation.

4. Results and discussion

4.1. Experimental results

The experimental results include data collected from the questionnaires and design sheets, as previously described. The questionnaire covered several dimensions: Interactivity, System Quality, Product Informativeness, Reality Congruence, Immersion, Cube Liking, Media Usefulness, Reuse Intention and Perceptions of AM. The design sheets were assessed by experts based on Novelty, Workability, Relevance, and Specificity.

Table 1
Criteria for creativity assessment.

		4	3	2	1
Novelty	<i>Originality</i>	Not expressed before (rare, unusual) And Ingenious, imaginative or surprising; may be humorous	Unusual, interesting; shows some imagination	Interesting	Common, mundane, boring
	<i>Paradigm relatedness</i>	Paradigm modifying (radical)	Paradigm modifying (high transformational)	Paradigm modifying (low transformational)	Paradigm preserving
Workability	<i>Acceptability</i>	Common strategies that violate no norms or sensibilities	Somewhat uncommon or unusual strategies that don't offend sensibilities	Offends sensibilities somewhat but is not totally unacceptable	Radically violates laws or sensibilities or totally unacceptable business practice
	<i>Implement ability</i>	Easy to implement at low cost or non-radical changes	Some changes or reasonably feasible promotions or events	Significant change or expensive or difficult but not totally impossible to implement	Totally infeasible to implement or extremely financially nonviable
Relevance	<i>Applicability</i>	Solves an identified problem that is directly related to the stated problem (do X to get Y, and Y is part of the stated problem)	Solves an implied problem that is related to the stated problem (do X to get an implied Y, which applies to the stated problem)	May have some benefit within a special situation and somehow relates to the stated problem (do X, which somehow relates to the stated problem)	Intervention is not stated or does not produce a useful outcome (no X) or (do X for useless Y)
	<i>Effectiveness</i>	Reasonable and will solve the stated problem without regard for workability (If you could do it, it would solve the main problem)	Reasonable and will contribute to the solution of the problem (It helps, but it is only a partial solution)	Unreasonable or unlikely to solve the problem (It probably will not work)	Solves an unrelated problem (It would not work, even if you could do it)
Specificity	<i>Completeness</i>	–	Comprehensive, with three or more parts from at least two of the 5 Ws + H (who, what, why, when, where, how), e.g. (what + when + where) or (what + what + why)	Contains two parts from different dimensions (5 Ws + H), such as, but not limited to (what + where), (what + why), (what + how), or three or more parts of only one of the 5 Ws + H (e.g., what + what + what)	Contains one or two parts from the same dimension and usually the “what” (e.g., (what) or (what + what))
	<i>Implicational explicitness</i>	–	Implication is clearly stated and makes sense (do X so that Y)	Implication is not generally accepted or is vaguely stated (do X, which solves a not-generally accepted Y) or (do X which solves a vaguely stated Y)	Implication is not stated, even though relevant (do X without a stated Y)

In this experiment, we evaluated the differences between the two groups of participants (using the AR applications and using a paper card) in multiple dimensions. Since the collected data is an orderly category data and does not meet the normal distribution, we have chosen Mann-Whitney *U* test. This non-parameter test method is suitable for comparing the median differences of the 2 independent samples, especially when the data distribution is unknown or the sample volume is small. By using the Mann-Whitney *U* test, we can effectively evaluate the difference between the score between the two groups to ensure the reliability and effectiveness of the results (Hollander et al., 2013).

After collecting the questionnaires, we analyzed the data which are presented in Table 2. The Cronbach's Alpha values for all constructs exceeded 0.70, indicating acceptable internal consistency. The score for

each dimension—Interactivity, System Quality, Product Informativeness, Reality Congruence, Immersion, Cube Liking, Media Usefulness, Reuse Intention, and Perceptions of AM—were calculated as the average scores of the questions associated with each dimension. Each dimension consists of several questions in the questionnaire, and the scores for these questions were aggregated to provide an overall score for each dimension.

We collected a total of 34 questionnaires, including 17 from the group using AR application and 17 from the group using cards. Fig. 8 presents the distribution of questionnaire scores across various dimensions for both the AR application (APP) and cards (Cards). The vertical axis represents the questionnaire scores (ranging from 1 to 7), while the horizontal axis displays the 9 evaluated dimensions:

Table 2
The results of usability questionnaire evaluation (N = 34).

Questionnaire	Group	Cronbach's Alpha	Mean	SD	Median	Mann-Whitney U	Z	Asymp. Sig. (2-tailed)
Interactivity	APP	0.823	5.38	0.96	5.40	57.00	-2.99	0.002
	Cards	0.764	4.18	1.14	4.00			
System Quality	APP	0.827	5.52	0.65	5.50	41.00	-3.53	0.000
	Cards	0.731	4.28	0.89	4.50			
Product Informativeness	APP	0.799	5.68	0.75	5.60	37.50	-3.65	0.000
	Cards	0.851	4.29	1.09	4.40			
Reality Congruence	APP	0.754	6.04	0.54	6.17	25.00	-4.08	0.000
	Cards	0.817	4.49	0.94	4.33			
Immersion	APP	0.842	5.67	0.84	6.00	54.50	-3.11	0.002
	Cards	0.856	4.38	1.12	4.00			
Cube Liking	APP	0.948	6.23	0.82	6.00	27.50	-4.05	0.000
	Cards	0.794	4.71	0.85	4.67			
Media Usefulness	APP	0.930	5.57	1.07	5.60	50.50	-3.20	0.001
	Cards	0.957	3.95	1.55	4.00			
Reuse Intention	APP	0.953	4.77	1.27	5.00	101.50	-1.43	0.157
	Cards	0.986	3.73	2.07	4.00			
Perceptions of AM	APP	0.929	5.76	0.96	6.00	129.50	-0.453	0.656
	Cards	0.890	5.75	0.74	5.60			

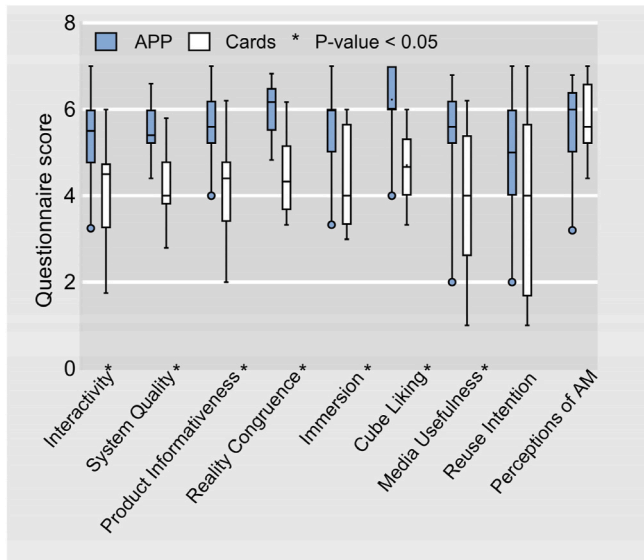


Fig. 8. Distribution of questionnaire scores across various dimensions for the AR APP and Cards.

Interactivity, System Quality, Product Informativeness, Reality Congruence, Immersion, Cube Liking, Media Usefulness, Reuse Intention, and Perceptions of AM. The blue boxes represent the score distribution for the AR application, and the white boxes represent the distribution for cards. An asterisk (*) indicates dimensions with statistically significant differences ($p < 0.05$) based on the Mann–Whitney U test. In most dimensions, the scores for the AR application are significantly higher than those for cards, particularly in Interactivity, System Quality, Product Informativeness, Reality Congruence, Immersion, Cube Liking, and Media Usefulness, highlighting the advantages of the AR application in these areas.

We employed the Mann–Whitney U test to examine whether significant differences exist in creativity scores between participants using the AR application and those using paper cards. Furthermore, in cases of substantial discrepancies in individual scores, we calculated the average score and conducted outlier checks to minimize individual bias. A total of 46 design sheets were collected, with 26 from the AR application group and 20 from the paper card group. Each dimension—Novelty, Workability, Relevance, and Specificity—was scored based on the average ratings of the individual components associated with that dimension, providing an overall score for each dimension within each design sheet (see Table 3).

Fig. 9 is comparison of creativity scores across 4 dimensions for the AR application (APP) and paper cards (Cards) groups. The vertical axis represents the creativity score, with scores ranging from 1 to 4 for Novelty, Workability, and Relevance, and from 1 to 3 for Specificity. The horizontal axis shows the 4 evaluated dimensions. The blue boxes represent the score distribution for the AR application, and the white boxes represent the distribution for paper cards. An asterisk (*) indicates

Table 3
Results of the Mann–Whitney U test for creativity.

	Group	Median	Mann–Whitney U	Z	Asymp. Sig. (2-tailed)
Novelty	APP	2.5	2861.50	−7.376	0.000
	Cards	2.0			
Workability	APP	3.0	2115.50	−8.897	0.000
	Cards	2.0			
Relevance	APP	3.0	1749.0	−9.645	0.000
	Cards	2.0			
Specificity	APP	2.5	2482.0	−8.225	0.000
	Cards	1.5			

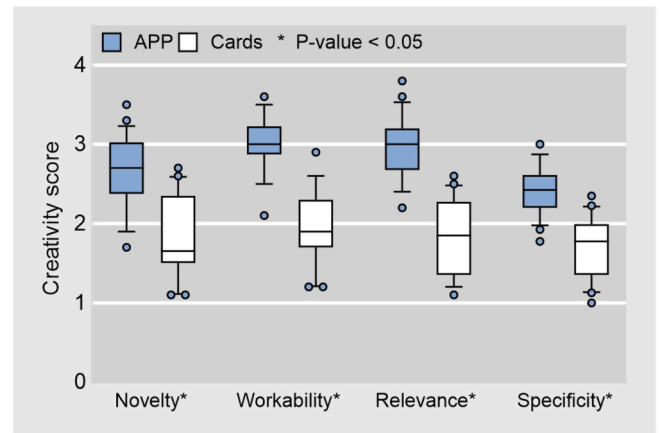


Fig. 9. Box plots of creativity score.

dimensions with statistically significant differences ($p < 0.05$) based on the Mann–Whitney U test. The AR application shows significantly higher creativity scores compared to paper cards across all 4 dimensions, particularly in Novelty and Relevance, suggesting the AR application’s potential to enhance these aspects of creativity.

To assess the consistency of the experts’ ratings on the dimensions of design creativity, this study employed the Intraclass Correlation Coefficient (ICC(2,k))(see Table 4). The analysis revealed high levels of inter-rater reliability across all four dimensions. Specifically, the Novelty comprising Originality and Paradigm Relatedness yielded an ICC of 0.80 with a 95 % confidence interval of [0.69, 0.88]; the Workability including Acceptability and Implement Ability showed an ICC of 0.78 with a 95 % confidence interval of [0.67, 0.87]; the Applicability and Effectiveness (Relevance) showed an ICC of 0.85 with 95 % confidence interval of [0.77, 0.91]; the Completeness and Implicational Explicitness (Specificity) exhibited an ICC of 0.82 with 95 % confidence interval of [0.73, 0.89]. All ICC values reached statistical significance ($p < 0.001$), indicating strong and consistent agreement among the 5 experts and supporting the reliability and validity of the expert evaluations.

4.2. Discussion

4.2.1. Usability enhancement of AR AM-based product design

The results of this experiment demonstrate that the AR application provides benefits over traditional methods. Significant differences (p -value < 0.05) were observed between the AR application and cards in the dimensions of Interactivity, System Quality, Product Informativeness, Reality Congruence, Immersion, Cube Liking, and Media Usefulness.

The significant advantage in Interactivity suggests that the AR application provides a more engaging platform for users, allowing them to interact with 3D models in real-time. This interactive experience enables users to explore complex design concepts more autonomously, which can lead to a deeper understanding and a more enjoyable learning experience. The high rating for System Quality indicates that the AR application delivers a reliable experience. For professional design tools, such system quality is essential to avoid technical distractions during the creative process. The significant difference in Product Informativeness reflects the AR application’s ability to present detailed information dynamically. Users can view models from multiple angles and zoom in

Table 4
Results of intraclass correlation coefficient (ICC(2,k)).

	ICC	P	CI95 %
Novelty	0,80	0.000	[0.69 0.88]
Workability	0,78	0.000	[0.67 0.87]
Relevance	0,85	0.000	[0.77 0.91]
Specificity	0,82	0.000	[0.73 0.89]

on components, providing a depth of information that is difficult to achieve with static cards. This helps designers understand their objects more thoroughly, enhancing design accuracy and effectiveness. The higher Reality Congruence score indicates that the AR application's realistic 3D visualization helps users bridge the gap between virtual models and real-world products. This realistic congruence allows users to assess design feasibility and applicability more intuitively, particularly valuable in complex fields like AM. The significantly higher Immersion score suggests that the AR application offers an experience that captures users' attention, enhancing focus and engagement in the design task. The higher Cube Liking score reflects users' positive response to the visual appeal of 3D models presented through AR. This visual engagement likely improves users' interest in exploring model details, fostering a stronger emotional connection with the design object. Such positive emotional experience can enhance users' acceptance and intention to use the design tool. The significant difference in Media Usefulness suggests that users perceive AR as a more effective design medium. With dynamic displays and interactive features, AR enables users to access information more quickly and accurately, making it a powerful tool for designers learning and understanding complex technologies.

For the dimensions of Reuse Intention and Perceptions of AM, while the mean scores for the AR application were slightly higher than those for paper cards, no statistically significant differences were observed. This may be due to the more extensive textual descriptions and examples provided on the paper cards, which could help participants better grasp the potential use cases and applications of AM. In contrast, the AR application currently lacks detailed textual information, a limitation that could be addressed in future iterations to improve user understanding and intention to reuse.

4.2.2. Creativity enhancement of AR in AM-based product design

In addition to improving AM knowledge, the results show that AR applications foster creativity among designers. The significant improvements in creativity dimensions—Novelty, Workability, Relevance, and Specificity—suggest that the AR application provides designers with an interactive, immersive platform that supports the ideation process. The functionalities allowing users to manipulate model sizes and visualize the assembly process provided designers with enhanced information about AM models, facilitating a more comprehensive comprehension of their characteristics. Figs. 10 and 12 show example idea sheets produced by participants using the AR application and cards.

Figs. 11 and 13 show participants brainstorming using the AR application and cards, respectively.

The AR application group produced a greater number of design sheets (26) compared to the card group (20). This difference suggests that the AR application may encourage users to generate more ideas, likely due to its engaging and immersive nature. The interactive features and real-time visualization capabilities of AR might have motivated participants to explore and document a broader range of creative concepts. This increased design output highlights AR's potential as a stimulating tool that supports both the quantity and quality of design ideation.

This study's findings can be interpreted through the lens of immersive learning and multimodal visualization. Although the AR system was used on a smartphone, it still allowed users to view and interact with 3D models in real space. This interactive and spatial experience supports



Fig. 11. Participants using AR application.

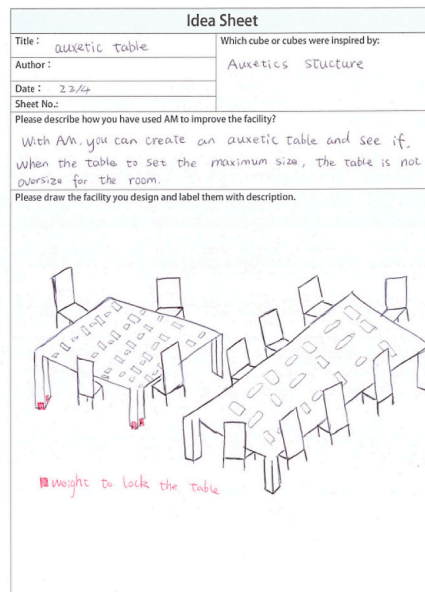
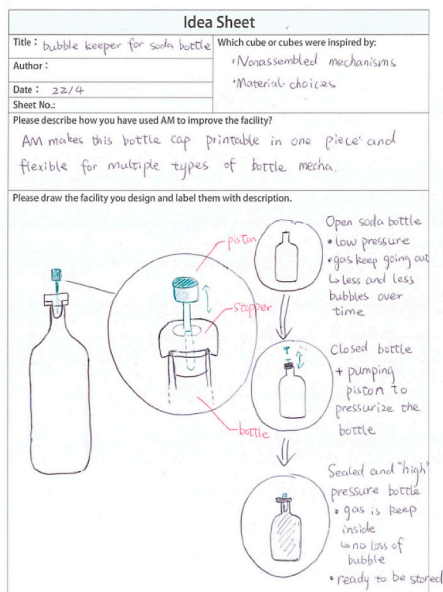


Fig. 10. Idea sheets produced by the participants used AR application.

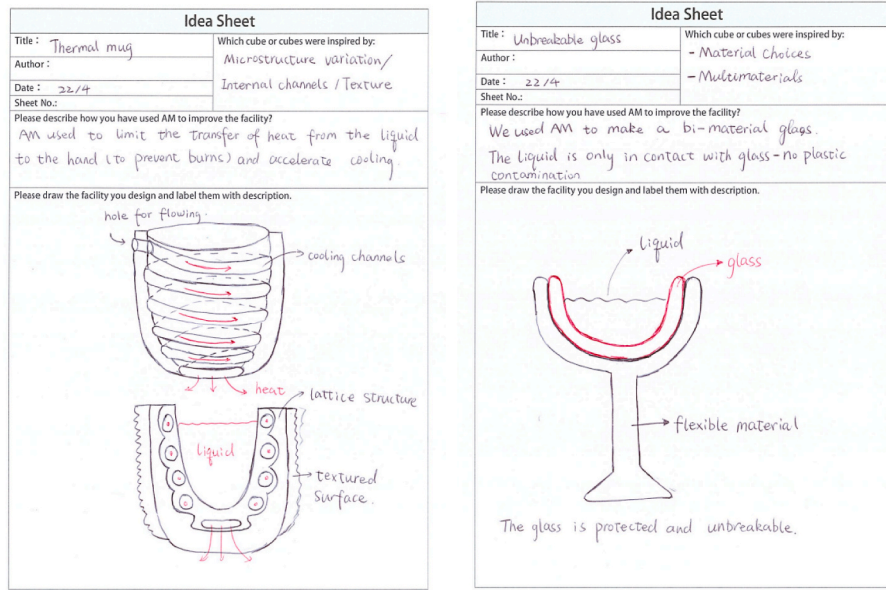


Fig. 12. Idea sheets produced by the participants used cards.



Fig. 13. Participants using cards.

immersive learning by encouraging active exploration and engagement with content in context.

The system also supported multimodal visualization by combining visual and spatial information. This may have helped participants better understand the structure of AM models and inspired new design ideas. These features—spatial interaction and multi-sensory input—likely contributed to the improved creativity observed in the AR group.

However, we also recognize that the observed effect may be partly due to the novelty of the AR experience. Since most participants had limited prior exposure to AR, the increased engagement and motivation might have influenced their performance. While this does not reduce the educational value of AR, future studies should explore whether these effects persist over time and with repeated use.

5. Conclusion and perspective

In conclusion, this study integrates AM with AR from a novel perspective, emphasizing the potential of AM. By leveraging AR’s interactive capabilities, this approach offers a fresh perspective on how complex knowledge can be effectively communicated. The integration of

AR enables learners to engage more deeply with intricate AM concepts, facilitating a more comprehensive and intuitive understanding of the technology. The experimental results demonstrate that using the AR application significantly improves designers’ comprehension of complex AM principles compared to traditional card-based methods. Participants also generated more innovative design solutions when interacting with AR models, indicating that the application fosters creativity in the conceptual design process. Furthermore, the AR environment provided clear advantages in usability, interactivity, engagement, and perceived usefulness, offering a more immersive and effective experience than traditional representations.

These findings carry practical implications for both product design and AM technology. Integrating AR into educational and professional design environments could improve learning outcomes for complex technologies such as AM. For instance, AR enables students to visualize intricate 3D structures, helping them build foundational skills in AM. In industry, AR may allow designers to iterate and refine designs more efficiently, supporting a more agile and creative product development process. This research suggests that AR is particularly beneficial in fields like AM, where visualization, understanding, and innovation of complex 3D structures are essential. The study also highlights the potential of AR to enhance designers’ knowledge and creativity during early product design stages. Through real-time interaction with AM models, designers can better understand and leverage the unique features of AM, resulting in a more effective and creative design process.

Despite the promising results, this study has certain limitations. The relatively small sample size (34 participants) limits the generalizability of the findings, and further research with a larger, more diverse participant group is needed to validate these results. The participant sample comprises solely 1st-year master’s students from ENSAM, which may limit the generalizability of the findings. These students possess foundational knowledge of AM but limited to no prior experience with AR technologies. This specific demographic was selected to target users with baseline AM understanding but minimal AR exposure, providing a clearer assessment of the AR application’s effectiveness in enhancing AM learning. Future research could extend the study to diverse populations with varied expertise levels and institutional backgrounds to validate and generalize the results. The questionnaire items used in this study were adapted from multiple established scales in the literature to comprehensively capture constructs related to AR and AM learning experiences. These items were carefully selected based on their theoretical

relevance and prior validation in comparable research contexts. However, this approach presents a limitation, as the validity and reliability of the combined instrument may be compromised without a dedicated validation. Due to practical constraints, a full validation was beyond the scope of the present study. Future research is encouraged to undertake rigorous validation of such integrated measurement. Additionally, the AR application in this study has limitations in presenting detailed text descriptions and examples compared to the cards. Future research could address these limitations by improving textual and illustrative content in AR environments. Meanwhile, we could also compare the use of the AR application with the real 3D cubes. To explore the potential of broader AM applications, the AR application includes a module that displays related AM models beyond the 14 cubes used in the main task. Participants noted that these supplementary models enriched their understanding of AM. Several also suggested incorporating examples of real-world AM products into the system, which we plan to implement in future work to increase the authenticity of the learning context.

While the present study demonstrates that the AR smartphone application enhances designers' understanding and creativity compared to static cards, it does not fully disentangle the effects of general interactivity from those specific to AR. To address this limitation, a follow-up study is underway comparing smartphone-based AR with AR delivered through head-mounted devices. The enhanced immersion and

interaction afforded by AR glasses will allow us to investigate the distinct contributions of AR features to learning and design outcomes. Features such as hand tracking and enhanced interaction capabilities could deepen user engagement and understanding of AM. In future work, we aim to further develop our AR application to provide designers with richer insights into AM technology, supporting creativity and improving the practical application of AM in design processes.

CRedit authorship contribution statement

Jinxue Cui: Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Fabrice Mantelet:** Supervision, Methodology, Data curation, Conceptualization. **Camille Jean:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Ruding Lou:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Frédéric Segonds:** Writing – review & editing, Supervision, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Questions	"1" = "strongly disagree" to "7" = "strongly agree"						
	1	2	3	4	5	6	7
Interactivity							
Through the interaction with the virtual cube presentation in the AR smartphone app (on the card), I can get an initial conceptual understanding of the cube.							
The virtual cubes presentation in the AR smartphone app (card) have remarkable interaction features.							
I am able to interact with the virtual cube presentation in the AR smartphone app (on the card) in order to get information tailored to my specific needs.							
The degree of interaction with the virtual cube presentation in the AR smartphone app (on the card) is outstanding.							
System Quality							
The AR smartphone app (card) is promptly responsive to my requests and provides good results.							
The AR smartphone app (card) performs its functions quickly and efficiently.							
The AR smartphone app (card) is reliable (it is always up and running, runs without errors, and does what it is supposed to do).							
The AR smartphone app (card) provides perfect and precise services in line with the purpose of the system.							
I assume no limitations or problems in using the AR smartphone app (card). The AR smartphone app (card) fully meets my needs.							
Product Informativeness							
The AR smartphone app (card) shows the information I expected.							
The AR smartphone app (card) provides detailed information about the cubes.							
The AR smartphone app (card) provides complete information about the cubes.							
The AR smartphone app (card) provides information that helps me in my design.							
The AR smartphone app (card) provides information to compare cubes.							
Reality Congruence							
The AR smartphone app (card) presents cubes impressively.							
Overall, I find that the AR smartphone app (card) presents cubes attractively.							
The design of the cubes is visually pleasant.							
The AR smartphone app (card) presents cubes visually appealingly.							
The AR smartphone app (card) presents the design of the cubes (e.g., colors, shapes) realistically.							
The AR smartphone app (card) presents cubes as if they were real.							
Immersion							
Deeply engrossed							
Absorbed							
My attention was focused							
Cube Liking							
Good							
Pleasant							
Likable							
Media Usefulness							
The AR smartphone app (card) enhances my ability to learn the knowledge more effectively.							
Using the AR smartphone app (card) saves me time.							
Using the AR smartphone app (card) improves the quality of my search for Additive Manufacturing.							
The AR smartphone app (card) enables me to acquire information more quickly.							
Overall, I find the AR smartphone app (card) is useful in my design experience.							
Reuse Intention							

(continued on next page)

(continued)

Questions	"1" = "strongly disagree" to "7" = "strongly agree"						
	1	2	3	4	5	6	7
I intend to reuse the AR smartphone app (card).							
I predict I will reuse the AR smartphone app (card).							
I plan to reuse the AR smartphone app (card).							
Perceptions of AM							
I feel able to explain the opportunities of AM to someone else.							
I feel able to give examples of objects that take advantage of AM opportunities.							
I feel capable of proposing ideas of innovative object exploiting the opportunities of the AM.							
I feel able to recognize objects applying the AM opportunities.							
I think I have mastered the AM opportunities.							

Data availability

Data will be made available on request.

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