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Article

IdeAM: A Serious Game to Foster Creativity in Additive Manufacturing

Eléa Conil[1], Camille Jean[1], Fabrice Mantelet[1], Claude Gazo[1], Jérôme Guegan[2], Stéphanie Buisine[3], Frédéric Segonds[1]

[1] *Arts et Métiers Institute of Technology, LCPI, Paris, France ;* [2] *Université Paris Cité, Université Gustave Eiffel, LaPEA, Boulogne-Billancourt, France ;* [3] *CESI, LINEACT, Nanterre, France*

elea.conil@ensam.eu; camille.jean@ensam.eu; fabrice.mantelet@ensam.eu; claude.gazo@ensam.eu; jerome.guegan@u-paris.fr; sbuisine@cesi.fr; frédéric.segonds@ensam.eu

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Abstract

This study investigates the potential of serious games (SG) to enhance creativity in additive manufacturing (AM). While AM offers unique opportunities to explore complex designs, traditional manufacturing methods often limit designers' creativity due to cognitive biases formed by years of using conventional processes. This research aims to introduce *IdeAM*, a SG designed to foster creativity in AM and help overcome these cognitive constraints.

The IdeAM game was developed using the DICE framework (Define, Imagine, Create, Evaluate) with iterative feedback from both users and experts. The game immerses participants in creative scenarios through its content, rules, and aesthetic, encouraging the exploration of AM's 4 key complexities as defined by Gibson: shape, hierarchical, functional, and material complexities.

To evaluate its effectiveness, participants were divided into focus and control groups. The performance was assessed based on 3 aspects: creative solution generation, AM technical potential use, and participant experience. The results show that *IdeAM* significantly improved participants' creativity and their ability to explore AM's technical potential. Additionally, participants reported higher motivation and engagement compared to the control group.

The originality of this work lies in its novel integration of creativity in AM into a serious game, an area that has received limited attention in existing literature. The impact of this study extends to future SG initiatives in AM, with implications for both educational and industrial applications.

1. Introduction

In industry, innovation is driving companies to take new technologies onboard quickly. Among these technologies, Additive Manufacturing (AM) has become widely adopted in today's manufacturing industry. It includes any component that is created from a digital model and then manufactured layer by layer by adding material. Now, beyond simple prototyping, this process makes it possible to create fully functional parts. It thus opens up an unprecedented level of freedom to manufacturers compared to material removal and forming processes which impose stricter design constraints [1, 2]. This is revolutionizing all areas of industry, particularly in the automotive, aeronautics, aerospace, and medical sectors. However, designers rely on methods and tools adapted to traditional manufacturing processes to generate ideas, design, and manufacture their products. These processes and tools cause misuse of AM complexities. For this purpose, design methods grouped under the term DfAM (Design for Additive Manufacturing) are developed.

Laverne et al. [3] notes that participants of an AM creativity session tend to self-censor due to the complexity of putting the project into practice. It is the participants' projection into future design stages that constrains them. Additionally, creative teams tend to rely on design habits shaped by their training and past experiences. Also, addressing the complexities of AM requires significant mental agility. It is why, in the early stages of product design, researchers have introduced various tools to incorporate AM-specific knowledge, such as card-based approaches or objects illustrating AM's technical possibilities, to emphasize the technology's potential and inspire concepts beyond the limitations of traditional manufacturing. However, those tools do not consider the participants' willingness to get involved and their motivation to change their thinking.

The objective of this paper is to present and evaluate a new serious game, *IdeAM*, specifically designed to foster creativity in AM. The game is designed to encourage AM creativity by integrating motivational strategies and accommodating various cognitive styles. The performance will be assessed based on 3 aspects: creative solution generation, AM technical potential use, and participant experience. Section 2 reviews the background on AM design support methodologies, creativity, and serious games, and introduces the research question. Section 3 details the method used to create the game, while Section 4 provides an overview of *IdeAM*. Section 5 describes the testing protocol employed to assess the game's effectiveness, and Section 6 presents and discusses the results. The conclusion summarizes the findings and offers recommendations and directions for future research.

2. Background

The design methodologies are mainly based on traditional manufacturing due to its anteriority and its wide use in industry [4]. The deep-rooted knowledge of traditional manufacturing practices among designers acts as a barrier to effective AM design [5]. This knowledge creates a cognitive bias, as designers have been trained in and continue to rely on the principles of traditional design processes [6]. To address these challenges, several research initiatives have introduced methodologies specifically aimed at facilitating design for AM, known as Design for Additive Manufacturing (DfAM) [4]. DfAM encompasses a set of strategies, tools, techniques, and guidelines that assist designers in optimizing their designs according to the unique characteristics of AM.

Booth et al. categorize DfAM into three key areas: AM technologies, DfAM guidelines, and design methods [7]. The first area focuses on the technological aspects of AM and present the boundaries of the technology to consider during product design, for example by presenting solutions to the volume constraints of machines [8]. These methodologies are very useful for the creation of CAD models. The second area present the specificities of the different AM processes [9]. These guidelines focus on the design phase between the creation of the CAD model and the manufacture of the prototype. The last one, design methods, can be divided into two categories: computational design tools and the general DfAM process methods. Computational design tools assist designers in incorporating the geometric freedoms enabled by AM technologies, as well as the constraints of the process. Examples include software for topological optimization. The general DfAM process methods rely for the entire design process. For instance, Laverne et al. propose a methodology that incorporates AM knowledge in the creative phase of the design process. This approach enables better anticipation, as costs are relatively low and the potential for changes is high [10].

In this early phase, various tools can help promote creativity in design sessions. General techniques like brainstorming and mind mapping are widely used, though they are not specifically tailored for AM. Some researchers have focused on more tangible tools that integrate AM-specific knowledge into the creative process. For example, card-based approaches have been used to highlight the potential of AM technologies, giving designers starting points that go beyond the constraints of traditional manufacturing [11, 12]. Other methods, such as the use of physical objects, also encourage designers to engage directly with AM's unique characteristics. By manipulating these objects, designers become familiar with AM's technical possibilities, which can spark creative ideas and new concepts [13-15]. For example, Lang et al. introduce 14 cubes representing AM opportunities derived from the four complexities identified by Gibson: shape, hierarchical, functional, and material complexities [16, 17]. Figure 1 presents two examples of these cubes: topology optimization (left) and auxetic structures (right). In topology optimization, AM enables the realization of complex organic geometries that are unfeasible with traditional manufacturing methods, thereby pushing the boundaries of design optimization. For auxetic structures, AM facilitates the modification of the Poisson's ratio, allowing the structure to transmit or absorb stresses through deformation and compression.

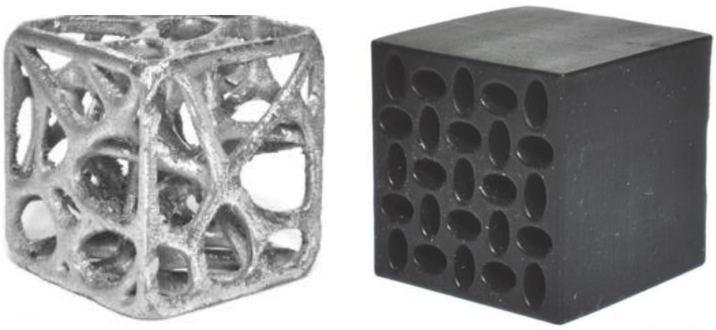

Figure 1. Example of inspirational cubes: Topology optimization (left) and Auxetics structure (right) [16]

However, those creative tools and methods face a limitation in their ability to foster two key factors essential for a productive creative session: motivation and cognitive style. Motivation can be intrinsic (driven by personal factors such as curiosity) or extrinsic (driven by external rewards like competition)[18]. Cognitive style refers to the unique ways individuals approach thinking, learning, and problem-solving. Gardner's theory of multiple intelligences suggests that there are different types of intelligence, such as linguistic, logical-mathematical, spatial, and emotional, that influence how people process information and solve problems in various contexts [19].

To address this challenge, serious games (SG) offer a potential solution. SG are games with a purpose other than entertainment [20, 21]. They take various forms such as card games, board games and video games. They help motivate players through ego gratification, adrenaline, social interaction and emotion and they allow the player to get involved into a learning dynamic without struggling [22, 23]. Previous research highlights the significant potential of serious games in many domain like science and mathematics [24] or management education [25]. SG are also already widely used in the specific field of engineering design and innovation [26-28]. For example, propositions have been made to trigger behavioural changes and increase fluidity of ideas with Lego bricks as a visualization tool [29], to encourage collaborative design learning by a knowledge trading game [30], or to learn AM opportunities with a mobile phone game [31].

Although SG have been successful in various fields, there remains a gap in the literature regarding their potential to enhance creativity in AM, particularly with respect to the critical factors of motivation and cognitive style. This article aims to fill this gap by addressing the question: How can a serious game foster creativity in AM? To answer this question, a new serious game, *IdeAM*, will be introduced and evaluated. *IdeAM* is specifically designed to stimulate creativity in AM by incorporating motivational strategies and considering diverse cognitive styles. The next section outlines the game's design methodology.

3. Method

For the design of IdeAM, we followed the generic Serious Game design process named DICE, which is structured in four key steps: Define, Imagine, Create, and Evaluate [32]. By following the process, we were able to systematically define the core goals, creatively explore potential design solutions, develop prototypes, and evaluate them. Figure 2 illustrate the process.

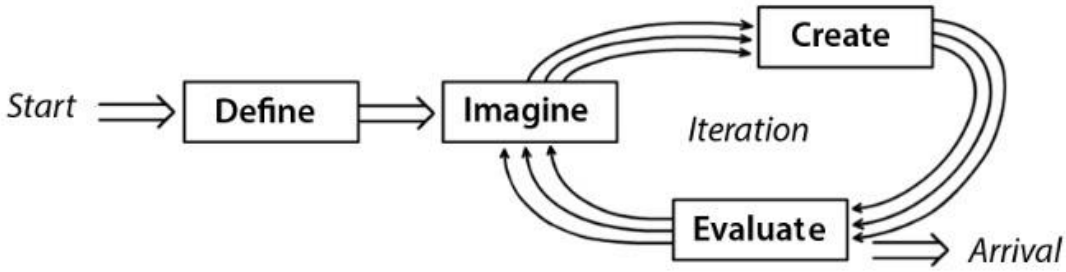

Figure 2. The SG design process DICE [32]

The Define stage focused on establishing clear learning objectives for the SG. Grounded in our review of the literature, the objectives were crafted to foster divergent thinking and encourage the exploration of the 14 AM opportunities of Lang et al [16]. Additionally, the design aimed to motivate participants by integrating engaging game dynamics and to accommodate various cognitive styles. This approach ensured that the game would be both accessible and stimulating for a diverse range of users.

In the imagination stage, brainstorming sessions were conducted to explore potential game concepts that could effectively integrate the defined objectives. 26 initial ideas, which were assessed for their ability to incorporate playful mechanics while conveying the serious content. From these, 4 promising concepts were selected for refinement, ensuring they met the project's specifications.

The creation and evaluation stages focused on materializing the selected concepts into tangible prototypes [33]. 4 prototypes were developed, tested, and iteratively improved based on continuous feedback from both users and experts. The evaluation process considered key aspects such as creativity, efficiency, coherence, engagement, accessibility, and collaboration. Over the course of three months, these 4 prototypes were merged and redesigned, ultimately resulting in a cohesive and effective SG, named *IdeAM*.

It is this final version of *IdeAM* that will be evaluated in this article, highlighting its potential as a tool for fostering creativity in AM. The next section presents the serious game IdeAM and outlines its key features.

4. Presentation of the SG IdeAM

In this section, we will provide a comprehensive overview of the game's content, rules, and the aesthetic in which it takes place. We will examine how these elements are specifically designed to align with the game's objectives and promote creativity in AM. The content encompasses the body of knowledge that IdeAM aims to convey to players. The rules are crafted to be both intuitive and challenging, incorporating a range of cognitive styles to ensure that players can easily engage with the game. Finally, the universe of IdeAM is designed to fully immerse players in an environment that enhances the overall experience. Figure 3 presents visuals of *IdeAM*, illustrating the box of the SG and the board game along with all its materials.

Figure 3. Illustrations of *IdeAM*

4.1 Content

The contents and information are the body of knowledge intended to be transmitted to the players. *IdeAM* content is focusing on the opportunities offered by AM [17]. It associate the 14 Opportunity Cubes that represents a specific opportunity offered by AM [16]. Figure 4 presents all those cubes categorized by shape complexity, hierarchical complexity, functional complexity, and material complexity. Detailed information for each element is available in the corresponding patent documentation [34].

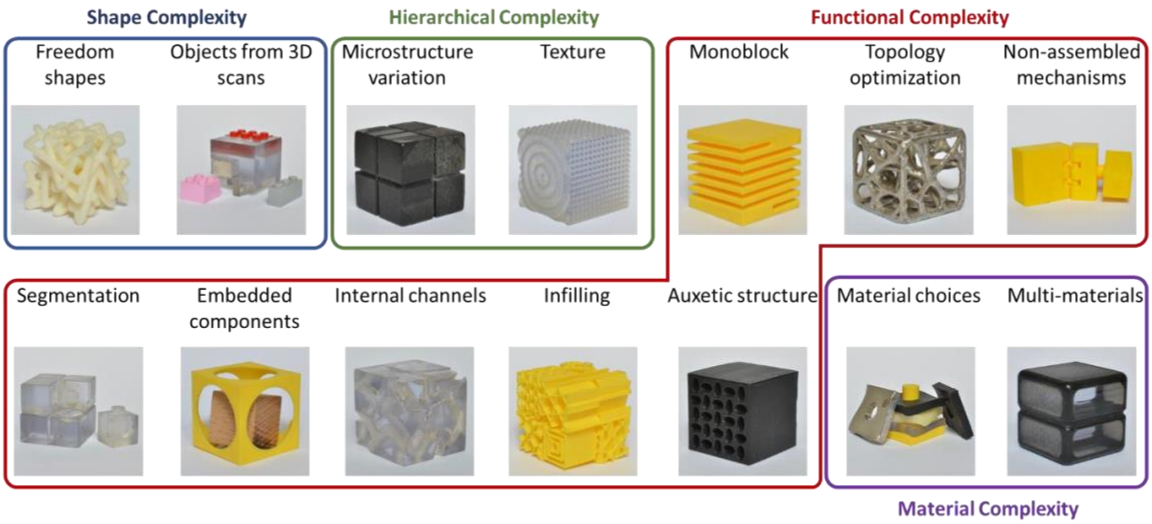

Figure 4. 14 AM opportunities objects from Lang et al. [16]

In addition to the 14 cubes, 52 Example Cards and 24 Paradigm Cards were developed. The Example Cards are closed-object cards illustrating AM products, designed based on an extensive analysis of diverse AM examples. Special attention was given to ensuring diversity across materials, sectors, and technical processes. The Paradigm Cards, on the other hand, feature prompts beginning with "What if" to stimulate creative thinking. For instance, "What if you had to design your object from a capture in real-time?". Figure 5 provides visual of these cards, including examples of Example Cards such as internal channel (1) and inclusion (2), as well as Paradigm Pards featuring "What if" prompts, such as examples (3) and (4).

(1) (2) (3) (4)

Figure 5. Visuals of Example Cards: internal channel (1), inclusion (2) and visuals of Paradigm Cards "what if" (3 & 4)

It is the association of opportunity cubes, example cards, and paradigm cards that encourages participants to engage in exchanges within their teams, simultaneously developing their AM knowledge and enhancing their creativity.

4.2 Rules

Rules are a set of instructions established to condition the smooth running of a game. They establish the faculties and constraints that each player must deal with. *IdeAM* aims to generate a maximum number of high-value ideas leveraging AM in teams of 1 to 6 players. To challenge the teams while avoiding negative reactions, the game incorporates a competitive structure designed to foster positive engagement.

The rules of *IdeAM* are inspired by the double-diamond model of creativity sessions and are structured to enable the dynamic co-construction of ideas. The SG punctuates the divergence phase with a series of emergence phases, energizing the group and promoting creative fluidity. At the start of each turn, each team randomly places their pawn near one of the 14 opportunity cubes. The gameplay is divided into two phases: an ideation phase and a motivation phase. During the ideation phase, participants collaboratively build their knowledge using paradigm cards and example cards associated with an opportunity cube. Players then individually propose ideas, which are subsequently enriched through team collaboration (emergence) and recorded on idea sheets. These idea sheets have been designed to take into account multiple intelligences (verbal / linguistic, logical-mathematical, visual / spatial, bodily / kinaesthetic, interpersonal, intrapersonal, musical, naturalist, existential and emotional) of Gardner et al [19]. Figure 6 provides an illustration of this idea sheet.

The game introduces a point-based system designed to energize gameplay and foster both competitive and collaborative dynamics. Teams earn points based on the technological, ecological, and economic aspects of their ideas, with evaluations conducted through a combination of peer, and self-assessment. This balanced approach leverages multiple perspectives to ensure fairness, encourage reflection, and promote constructive critique among participants. Additionally, during the divergence phase, teams are encouraged to interact with one another through various mechanisms. For instance, they may observe or "spy" on the ideas generated by other teams and use this information to refine or improve their own concepts.

This interactive element not only stimulates creativity by exposing players to a wider range of ideas but also fosters a dynamic and engaging atmosphere.

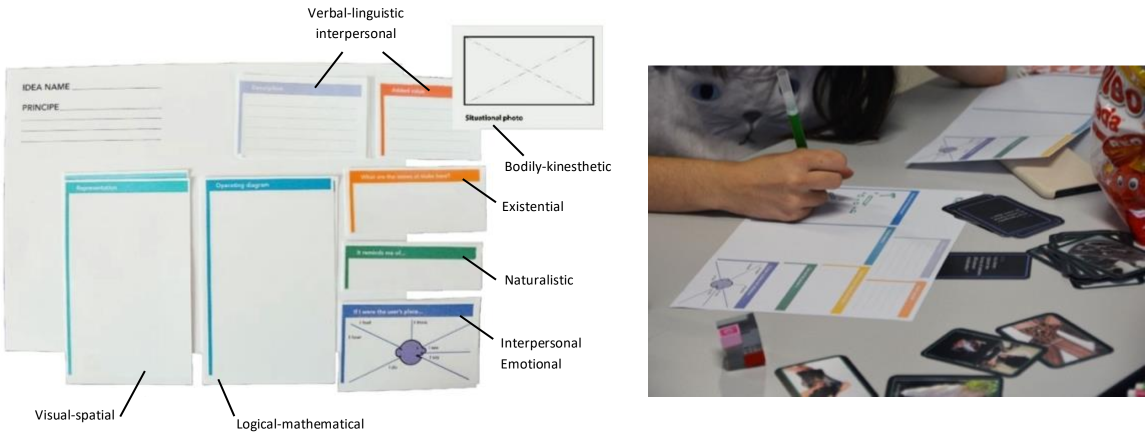

Figure 6. Idea sheet of *IdeAM*

4.3 Aesthetic

Aesthetics refer to the visual and thematic elements that shape the SG atmosphere and enhance the player's engagement and immersion. *IdeAM* is set in a science fiction (SF) space environment, where players take on the role of a crew aboard a commercial space station, equipped with advanced additive manufacturing machines, and face a variety of challenges. This SF theme is intricately embedded into every aspect of the game's design from the layout of the board to the narrative-driven cards and pawns, and the overarching storyline. The choice of this universe is not arbitrary; it is deeply rooted in cognitive and creative theory. By immersing players in an environment far removed from everyday realities, the SF universe fosters a "what if" mindset, encouraging lateral thinking and divergent idea generation [33]. Furthermore, the SF context provides players with the freedom to explore novel scenarios and experiment with imaginative solutions in a risk-free environment.

5. Proposal validation

We tested IdeAM by organising a creative session on an imposed subject. The subject was the design of a scooter of the future using AM opportunities. The experiment took place over one half day and was organised over 2 creativity sessions which took place in parallel, one with the IdeAM serious game, the other one using only the AM opportunity cubes [16]. The performance was assessed based on 3 aspects: creative solution generation, AM technical potential use, and participant experience.

5.1 Test conduct

A total of 33 master's students in engineering and design participated in the study. They were divided into 8 groups, each consisting of 3 to 5 students, with an intentional distribution of designers, engineers, and participants with advanced expertise in AM within each group. 5 groups (21 participants) worked with the IdeAM serious game and formed the focus group, while 3 groups (12 participants) worked with the AM opportunity cubes and constituted the control group. The experiment took place as presented in figure 7.

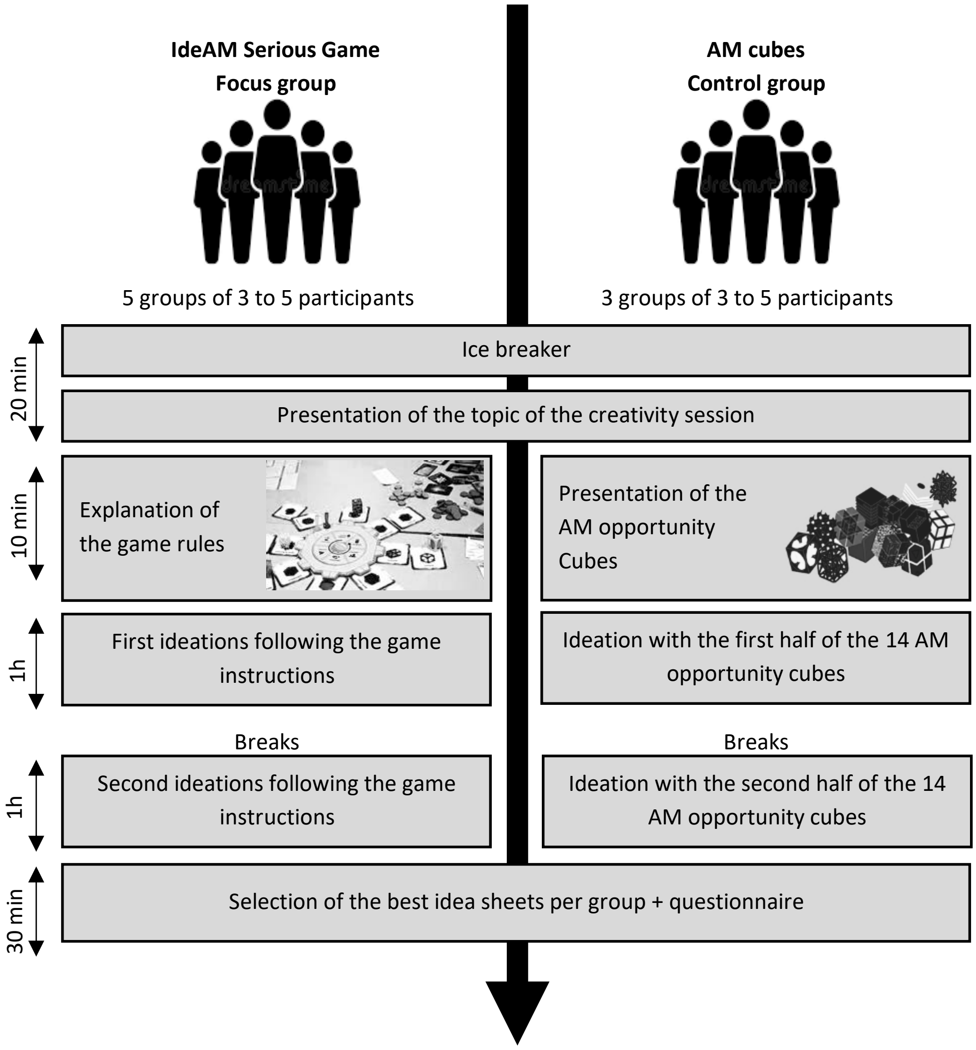

Figure 7. Test protocol

After a common icebreaker, all the groups got a presentation to introduce the topic of the creativity session to build a common knowledge base on the subject of the scooter of the future. Then the 5 focus groups got explanations of *IdeAM* rules and played a first game round to fully integrate them. On their side, the 3 control groups got a presentation of the 14 AM opportunity cubes. Following these preparatory activities, 2 creativity sessions of 1 hour each were conducted. During these sessions, the facilitator encouraged all participants across the groups to stay engaged and productive. For the focus groups, the creativity sessions were conducted utilizing *IdeAM*. In contrast, the control groups generated ideas using only the 14 AM opportunity cubes as stimuli. At the conclusion of the creativity sessions, each group selected their best idea sheets for expert analysis, and all participants completed a feedback questionnaire.

5.2 Creativity and AM evaluation grids

A panel of 4 experts analysed each idea sheet. The panel consisted of professors in Innovation Engineering with 20 to 30 years of experience, highly skilled in evaluating creativity. Each idea sheet was assessed for creativity using four criteria adapted from [35, 36]: relevance, improvement, elegance, and vision. Additionally, the potential for AM was evaluated based on four criteria derived from [17]: geometrical complexity, hierarchical complexity, functional complexity, and material potential. A summary of these criteria is provided in Table 1.

Table 1. Evaluation grid

Creativity	
Relevance	Does the idea meet the requirements of the problem from a use and performance point of view? (For example, the concept seems to do what it is supposed to do, the concept seems easy to use, the concept meets the objectives)
Improvement (incremental innovation)	Does the concept draw on external knowledge to improve the existing product? (For example, does the concept draw attention to gaps in existing products, does the concept show how existing products could be improved, does the concept use existing knowledge to generate novelty)
Elegance	Is the idea elegant because the solution is at the same time efficient, sparing and intellectually satisfying, hence a certain aesthetic feeling? (For example, one can see immediately that the concept makes sense, the concept is well finished and skilfully executed, the concept Is surprisingly simple and is "smart")
Vision (disruptive innovation)	Does the idea propose new ways of approaching existing problems In order to innovate? (For example, the concept is designed with new bases, the concept transforms problems into advantages, the concept brings a product that does not yet exist)

Additive Manufacturing	
Geometrical potential	Does the idea highlight the possibility of achieving any geometry through the use of additive manufacturing? (For example, complex shapes, unique shape integration, surface properties)
Hierarchical potential	Does the idea highlight the possibility to improve the structural performance of the product through additive manufacturing? (For example, weight reduction, shape optimization, improvement of mechanical properties (density, hardness, strength, adhesion))
Functional potential	Does the idea highlight the contribution of new functions thanks to additive manufacturing? (For example, added secondary functions, modification of product functions over time, multi-product in one)
Material potential	Does the idea promote the use of several materials thanks to additive manufacturing? (For example, multi-material parts, choice of material independent of the design)

5.3 Participant experience evaluation

Each participant completed a questionnaire designed to evaluate their user experience with *IdeAM*. The questionnaire solicited feedback on both positive and negative aspects of the game, focusing on key areas such as creativity, learning, engagement, accessibility, and collaboration. Participants were also asked to provide comments regarding their overall impressions of the game as well as suggestions for improvements. To complement the participant feedback, the facilitator observed and documented participants' behaviour during the sessions. These observations included how participants interacted with the game mechanics, their level of enthusiasm and focus, and the dynamics within and between teams. The facilitator's notes provided additional qualitative insights, capturing behaviours that might not have been explicitly mentioned in the written feedback.

6. Results

In total, 104 idea sheets were created across all groups during the study. Of these, 73 were produced by the focus group, with each of the 5 focus groups contributing approximately 15 idea sheets on average. The remaining 31 idea sheets were developed by the control group, which consisted of 3 groups, each contributing around 10 idea sheets on average. An example of one of the idea sheets is provided in Figure 8, showcasing the format and content expected from participants.

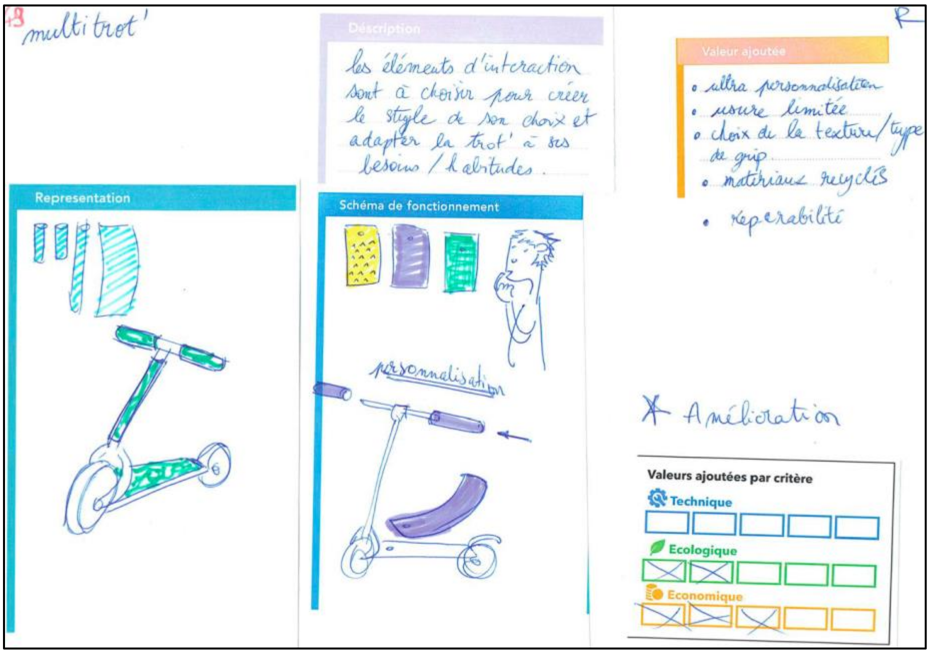

Figure 8. Example of idea sheet

A total of 44 idea sheets were selected for evaluation, with 28 chosen by the focus groups and 16 by the control group. To assess the quality of the selected ideas, each expert was tasked with evaluating the sheets based on the 4 creativity criteria and the 4 AM criteria defined in section 6.2. Each of these criteria was evaluated using a 5-point Likert scale, ranging from "Strongly Disagree" (-2) to "Strongly Agree" (+2). We choose a 5-point Likert scale based on research that supports its balance of reliability, validity, and user-friendliness including a neutral midpoint [37, 38]. The results of these evaluations were systematically analyzed using SPSS, a robust statistical software. This tool facilitated a thorough comparison of the ideas generated by the two groups, ensuring statistical rigor and reproducibility in the analysis.

6.1 Creative solution generation

The results of the evaluations of the creativity criteria are presented in the table 2.

Table 2. Creativity Criteria

Creativity criteria	Cronbach's alpha	Ideas Focus Group (n=28) mean (stdev)	Ideas Control Group (n=16) mean (stdev)	Delta	t	ddl	Sig. (bilateral)
Relevance	α = 0,629	0,52 (0,14)	-0,52 (0,17)	1,04	-4,526	42	p < 0,001
Improvement	α = 0,622	0,38 (0,15)	-0,45 (0,17)	0,83	-3,517	42	p = 0,001
Elegance	α = 0,730	0,5 (0,16)	-0,56 (0,22)	1,06	-3,88	42	p < 0,001
Vision	α = 0,726	0,54 (0,13)	-0,95 (0,15)	1,49	-7,194	42	p < 0,001

The results in Table 2 provide evidence of the impact of *IdeAM* on creativity criteria. The Cronbach's alpha coefficients ($\alpha > 0.6$) indicate acceptable levels of internal consistency among the ratings provided by the 4 experts. This suggests that the experts demonstrated reliable agreement in their evaluations. The standard deviations show that expert ratings for the focus group (which used the SG) were more consistent compared to the control group. Mean scores for all creativity criteria were higher in the focus group, with the most significant differences observed in the "Vision" criterion ($\Delta = 1.49$, $p < 0.001$), followed by "Elegance" ($\Delta = 1.06$, $p < 0.001$) and "Relevance" ($\Delta = 1.04$, $p < 0.001$). These differences highlight the SG role in fostering more creative ideas. A paired t-test was conducted to evaluate the significance of these differences. The null hypothesis, which assumes that IdeAM has no effect on creativity scores, was rejected for all criteria ($p < 0.05$).

Based on these findings, the higher mean scores across all criteria, along with significant t-test results and consistent expert ratings, confirm that *IdeAM* effectively fosters creative solution generation compared to the traditional approach used by the control group

6.2 AM technical potential

The results of the AM technical potential are presented in the table 3.

Table 3. AM technical use

AM technical potential criteria	Cronbach's alpha	Ideas Focus Group (n=28) mean (stdev)	Ideas Control Group (n=16) mean (stdev)	Delta	t	ddl	Sig. (bilateral)
Shape potential	α = 0,760	0,79 (0,12)	-0,30 (0,18)	1,09	-5,296	42	p < 0,001
Hierarchical potential	α = 0, 697	0,69 (0,14)	-0,50 (0,17)	1,19	-5,317	42	p < 0,001
Functional potential	α = 0,725	0,24 (0,12)	-0,80 (0,16)	1,04	-5,174	42	p < 0,001
Material potential	α = 0,805	0,16 (0,15)	-0,78 (0,3)	0,94	-3,089	42	p = 0,004

The results in Table 2 provide evidence of the impact of IdeAM on AM technical potential criteria. Each criterion's reliability was assessed using Cronbach's alpha, with all values exceeding 0.6, indicating acceptable internal consistency among expert ratings. The focus group, which utilized *IdeAM*, outperformed the control group across all criteria, as evidenced by significantly higher mean scores. The most notable improvements were observed in hierarchical potential ($\Delta = 1.19$, $p < 0.001$) and shape potential ($\Delta = 1.09$, $p < 0.001$), reflecting enhanced abilities in designing ideas suitable for AM applications with complex structures and adaptable shapes. Functional potential ($\Delta = 1.04$, $p < 0.001$) and Material potential ($\Delta = 0.94$, $p = 0.004$) also showed significant increases, although to a lesser extent.

Based on these findings, the higher mean scores across all criteria, along with significant t-test results and consistent expert ratings, confirm that *IdeAM* effectively fosters AM technical potential solution generation compared to the traditional approach used by the control group. The observed increase in results indicates that the game not only facilitated better learning about the opportunities of AM but also enabled participants to reinvest this newly acquired knowledge directly into the generation of innovative ideas.

6.3 Participant experience

At the end of the experiment, participants provided handwritten feedback about their experiences with *IdeAM* or the AM cubes. This feedback was transcribed and analysed to identify recurring themes and gain deeper insights into their perceptions. Additionally, the facilitator observed and documented participants' behaviour during the sessions, providing further context to the analysis.

The 3 most frequently mentioned expressions by the IdeAM group were ‘‘fun learning,’’ ‘‘enhancing AM knowledge for creativity,’’ and ‘‘positive competition.’’ A thematic analysis further uncovered three key aspects of participants' experiences: creativity and learning experience, engagement, and collaboration.

Creativity and the learning experience: participants reported that *IdeAM* played a significant role in transforming their perspectives and enhancing their understanding of AM. Comments such as “This game makes me think differently, and above all, it changed my vision of AM” and “IdeAM is a beautiful interactive game that helps to have an exhaustive view of AM possibilities” highlight the game’s impact on encouraging innovative thinking. Participants also emphasized the educational value of *IdeAM*, as reflected in statements like “It is very interesting to see the different possibilities of physical realizations with additive manufacturing,” “I really like the underlying learning and creative method,” and “It’s good to see a game that integrates diverse cognitive styles, it allows everyone to contribute in their own way.” These responses underscore how the *IdeAM* approach not only fosters creativity in AM but also enhances participants’ motivation and deepens their understanding of AM.

Engagement: participants exhibited high levels of involvement and motivation throughout the sessions. Facilitator observed their reluctance to take breaks, which is uncommon in such activities. Also, some participants noted that the half-day session was insufficient to explore all 14 opportunities and recommended extending the duration to a full day. Last, while the ideation process initially progressed slowly as participants familiarized themselves with the rules, the pace of idea generation accelerated significantly once they became accustomed to the game’s mechanics. In contrast, the control group began ideation more quickly but ran out of ideas and inspiration within 45 minutes. This suggests that *IdeAM* sustains engagement to support creativity in AM.

Collaboration: *IdeAM* improved team dynamics by fostering active communication, interaction, and cooperation among participants. Unlike the control group, which reported limited discussion during ideation, *IdeAM* users engaged in frequent exchanges of ideas, shared idea sheets, and collaboratively refined their concepts. The game mechanics also contributed to cross-team collaboration. For example, the “spying” feature allowed ideas from one team to be shared and further developed by another, ensuring promising concepts were not overlooked. This highlights the potential of structured gameplay to promote idea sharing, and refinement.

7. Discussion

The results of this study underscore that *IdeAM* promotes the generation of creative solutions, supports the exploitation of the technical potential of AM, and improves participant experience with a better engagement and collaboration. Despite these promising findings, several limitations and perspectives for future research should be noted.

First, one of the primary limitations of this study lies in the characteristics of the participant group. The sample consisted exclusively of individuals aged 20–30 years, all of whom were not reluctant to be creative. This homogeneity restricts the generalizability of the findings to broader users in the industry. Future studies should explore how *IdeAM* can perform in such contexts. Moreover, investigating its application in professional settings with varying organizational cultures and demographics may provide further insights, particularly for companies looking to incorporate gamification in creative work. Second, the impact of the global health crisis of 2019 has accelerated the need for companies to adapt their work methods, emphasizing remote and hybrid collaboration tools. The use of a SG like *IdeAM* could be therefore challenging. Given that *IdeAM* has potential for digitalization, future research should develop and test a virtual version of the game. Third, participants noted the strong rhythm of the SG, indicating a need for adjustments in term of time. Conducting a series of tests to determine the optimal duration of gameplay could enhance the experience and outcomes.

Lastly, the rating scale used for evaluating creativity emerged as an area for improvement. The current scale, which ranges from negative to positive evaluations, may inadvertently bias judges towards a critical perspective. Transitioning to a more positive-oriented scale, such as a 1-to-5 system, could provide a more balanced framework for assessing creativity.

Future work can therefore focus on diversifying participant profiles, testing digital versions of *IdeAM*, and refining the gameplay mechanics and evaluation metrics.

8. Conclusion

This study highlights the potential of *IdeAM*, a SG designed to foster creativity in AM. By addressing the cognitive biases that designers develop through years of using conventional processes, *IdeAM* provides a structured and engaging platform for exploring AM's unique capabilities. Developed using the DICE framework, *IdeAM* integrates content, rules, and aesthetics to immerse participants in creative scenarios, enabling them to fully investigate AM's 4 key complexities: shape, hierarchical, functional, and material.

The results demonstrate that *IdeAM* significantly enhances creativity and the application of AM's technical potential. Participants in the focus group, who engaged with the game, generated more innovative and technically advanced solutions than the control group Participants using *IdeAM* produced ideas with greater relevance, elegance, and vision while demonstrating a deeper understanding of AM's complexities, such as shape, hierarchical, functional, and material potentials. Additionally, *IdeAM* fosters engagement, collaboration, and motivation among participants driven by the game's dynamic and aesthetic. These findings underscore the effectiveness of *IdeAM* as a tool to overcome cognitive constraints and support creative thinking in AM.

This research contributes to the limited body of literature on the intersection of serious games, creativity, and AM. The insights gained from this study pave the way for further exploration of SGs for creativity and AM, with potential applications in both academic and industrial contexts.

9. Funding information

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