IdeAM Running Quiz: A Digital Learning Game to Enhance Additive Manufacturing Opportunities Discovery

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Abstract—This paper provides a description of IdeAM Running Quiz, a learning game aiming at enhancing Additive Manufacturing (AM) opportunities learning. Firstly, a review of the literature on the Design and Additive Manufacturing methodologies and the educational effectiveness of learning games is presented. Then, the steps involved in the design of IdeAM Running Quiz game are introduced. IdeAM Running Quiz is a digital learning game inspired by arcade games. It is an infinite race where the player will have to choose the right path that will allow him to advance. It features examples of objects that can be made with AM as well as AM opportunities. For this research, we have conducted an experiment aiming at evaluating the effectiveness of IdeAM Running Quiz on AM opportunities learning, and satisfaction provided by playing it. This experiment has shown that IdeAM Running Quiz helps player to understand additive manufacturing opportunities. The experiment has also shown that participants like to play IdeAM Running Quiz and would recommend it for someone who wants to discover AM opportunities.

Keywords—additive manufacturing, learning, gamification, digital learning games

1 Introduction

To face the 4th industrial revolution, companies must adopt new innovative technologies that will allow them to remain competitive. Among these technologies, additive manufacturing is a process that can potentially allow companies to control costs, improve quality and reduce the development time of their products during the upstream phases of design [1]. Additive manufacturing includes manufacturing processes that generate layers of material deposited and added on top of each other [2].

Additive Manufacturing processes impact the automotive, aerospace, and medical industries, and open new avenues in product design. This technology is different from traditional manufacturing processes. Thus, due to designers' lack of knowledge about AM, cognitive biases complicate the generation of innovative designs that consider AM opportunities [3]. To address this issue, specific design methods have been developed under the name of DwAM and DfAM (Design with / for Additive Manufacturing). These methods allow designers to innovate by taking additive manufacturing into account by integrating AM knowledge during the preliminary design phases [3]. Lang et al., have defined 14 capabilities of additive manufacturing that have been illustrated through 3D cubes to make these capabilities tangible [4]. In 2020, a Learning game (IdeAM) using the cubes was designed to enhance creativity by learning with AM opportunities [5]. With the COVID 19 crisis, designers have faced the issue of remote work. Thus, a digital Learning game, playable remotely had to be developed.

The objective of this paper is to present and to evaluate a new digital learning game build to strengthen additive manufacturing learning by playing with additive manufacturing opportunities. Section 2 focuses on a literature review on Design and Additive Manufacturing methodologies, as well as Learning and digital Learning games. Based on these findings, Section 3 introduces our research question. Section 4 and 5 describe the game creation and its prototyping. Section 6 provides the testing protocol adopted to assess the effectiveness of the digital learning game. Section 7 provides a presentation and discussion of the results. Finally, a conclusion ends this paper and provides recommendations and suggestions for future research.

2 State of the art

2.1 Design and additive manufacturing

Thanks to advances in materials’ properties and computer-aided design systems, it has become possible to make functional parts for final-use applications with additive manufacturing. Additive manufacturing enhances creativity during the design process and enables fast product development and reduction in tooling costs. However, due to a lack of design support tools during early stages, designers fail to capitalize on the design freedom offered by additive manufacturing [6]. To address this issue, methods and tools are developed to facilitate the discovery of additive manufacturing to allow designers to fully use the opportunities offered by additive manufacturing.

In this section, we will introduce three methodologies for design and Additive Manufacturing: Design for and With Additive Manufacturing which are complementary methodologies for convergence and divergence design phases and Design by AM which is a global methodology based on DfAM and DwAM considering every phase of the product design.

Design with/for additive manufacturing. To take advantage of additive manufacturing processes, it is necessary to identify their specific manufacturing capabilities as well as their manufacturing constraints [7]. In order to allow the specificities of additive manufacturing to be considered during the design stage, methods and tools have been developed and grouped under the name of Design for Additive Manufacturing (DfAM). These methods and tools give access to additive manufacturing knowledge to designers in order to enable them to consider all the AM specificities [8].

Design with Additive Manufacturing is a methodology developed by Lavern et al. (2016) adapted from Design with X methodology [9]. It aims to provide designers with knowledge about Additive Manufacturing during the upstream design phases. The objective of this methodology is to inspire designers through innovation so the product they are developing will always include innovative aspects [10].

Figure 1 presents the inclusion of the DfAM and DwAM methodologies in the design process. DwAM allows, starting from a problem, to work on a divergence phase to generate a maximum of ideas inspired by AM. The DFAM allows to work on a convergence phase to concretize these concepts and to propose innovative solutions.

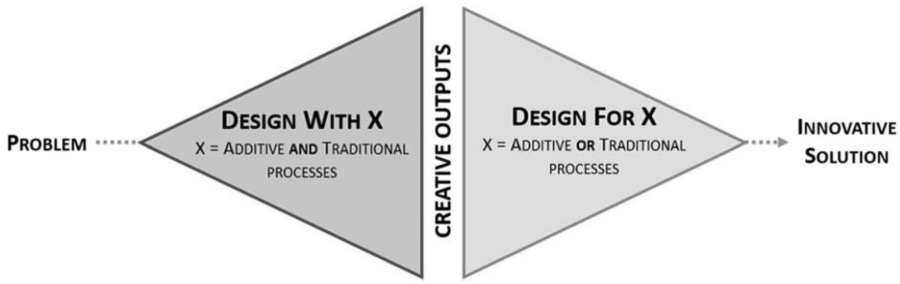

Fig. 1. DwAM and DfAM methodologies (Laverne et al., 2016)

A DwAM methodology to classify AM capabilities has been developed, based on:

- Gibson's 4 complexities: Shape complexity, Hierarchical complexity, Functional complexity and Material complexity [1]
- The TRIZ's 40 principles of innovation

Thus, based on Lang et al. [11] 14 capabilities of Additive Manufacturing have been identified and classified in relation to Gibson's complexities. For each complexity, the capabilities are listed below:

- Shape complexity: Geometric freedom, 3D Scan
- Hierarchical complexity: Microstructure variation, Texture
- Functional complexity: Monoblock, Topological optimization, Pre-assembled mechanism, Segmentation, Inclusion, Internal network, Internal structure, Auxetic structure
- Material complexity: Material choice, Multi material

These 14 capabilities have been modelized as manipulable cubes that aim to illustrate the AM capabilities [4]. Figure 2 represents an example of one of those cubes showcasing the topological optimization capability. Topological optimization enables finding the optimal way to distribute matter to reduce parts weight while keeping it mechanical properties. Parts manufactured using topological optimization often look like the cube shown in Figure 2. Thus, by manipulating the cube, users can familiarize themselves with how a part manufactured with topological optimization looks like.

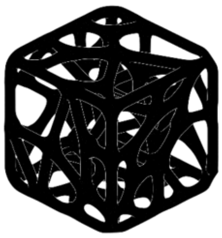

Fig. 2. D Model for topological optimization capability

We have created a set of images that can be associated with each of the cubes representing AM capabilities. The association of the images with the cubes will be used as a game mechanic in the learning game that we will present in the fourth section.

Design by additive manufacturing. Design By Additive Manufacturing is a methodology that promotes innovation by considering AM process from the early design stages. This model includes 5 steps: Knowledge Synthesis, Product Specification, Concept Generation, Design & Evaluation and Control. According to Segonds (2018), "The Knowledge Synthesis phase aims to capitalize and then exploit the necessary knowledge related to the product and/or the AM process" [3]. This step includes 4 sub steps: Analyse the problem, Identify Knowledge, Search Knowledge, Share Knowledge. The goal of the learning game we are developing is to share the knowledge that has been synthesized and modeled through Lang's 14 opportunities. Our work is therefore part of the Knowledge Synthesis phase of the DbAM methodology.

2.2 Edutainment: Play and learn

According to Egenfeldt-Nielsen et al., edutainment is an amalgamation of "education" and "entertainment". It is a broad term covering the combination of educational and entertainment use on a variety of media platforms [12].

Educational Games are games designed with educational target [13]. They can be intended for children, students or professionals. They take various forms such as card games, board games and video games [14]. They help motivate the player through ego gratification, adrenaline, social interaction and emotion and they allow players to get involved in a learning dynamic [15]. Learning games can help players to understand new content and overcome new challenges through mechanisms like achievement, peer interaction, and immersion. Through gameplay, difficult content becomes more accessible to students, allowing them to engage with subjects that initially cause anxiety or are not attractive. Digital serious games allow players not only to learn but also to help them develop problem solving skills through their interactive aspect [16].

Video games are one of the most popular entertaining activities. 48% of Europeans have played video games [17]. It allows players to feel motivated, develop skills social life [18]. Since the 80's, researchers have been interested in learning through video games and many learning videos games have been developed and commercialized since then [19]. They are called "digital learning games" or "digital serious games". These games are based on the idea that there are methodologies for learning: Observation, Questioning, Doing and Playing [20]. Learning on a medium using innovative technologies also serves to arouse the curiosity of the players and thus generate interest [21].

Researchers recognize that some issues remain regarding the use of video games for education. More particularly, the perception of video games influences the learning experience. Then, depending on how users are reluctant to video games, learning can be affected [12]. Also, it can be assumed that engagement and efficiency in learning through digital learning games depend on the game design [22]. However, according to Egenfeldt-Nielsen *et al*. learning outcome from the educational use of digital learning games are positive and promising. A study conducted by Levin et al. showed that "Video games are motivating, engaging, and ultimately successful in teaching children the planned math concepts. Video games may be especially suitable for teaching ways of approaching math that cater to individual differences." [23].

Concerning the design of those games, according to Juric et al. [22], there are four mandatory features to implement when designing a game:

- Goal – relates to the specific result that players aim to achieve. It provides players with a sense of purpose.
- Rules – set up ways of accomplishing goals. Rules facilitate creativity and strategic thinking.
- Feedback – informs players on their proximity to the goal. It can be implemented through scores, levels, or the level of progress. Real-time feedback serves as a promise that the goal is accomplishable and boosts motivation for playing.
- Voluntary participation – players voluntarily accept goals, rules, and feedback. Starting a game and quitting it in one's own rhythm makes otherwise stressful and challenging activity perceived as pleasant and safe.

Therefore, in this article we will present a work that is at the intersection of the fields studied in this state of the art. Thus, we will present the concept of a digital learning game for design and additive manufacturing.

3 Research question and methodology

This article will answer the following question: how can a digital Learning game enhance the discovery of opportunities in Additive Manufacturing?

To answer this question, we have created a digital learning game and measured its effectiveness on player learning. To assess the effectiveness of the game, we used a self-assessment methodology based on the participants' perception of their AM opportunities knowledge. Each participant of the test will have to answer twice a questionnaire about their AM opportunities knowledge, before and after playing the game.

4 Game creation

In order to design the Learning game, we used the Design Thinking approach, which involves five steps, Empathy, Define, Ideation, Prototype and Test [24], [25], [26].

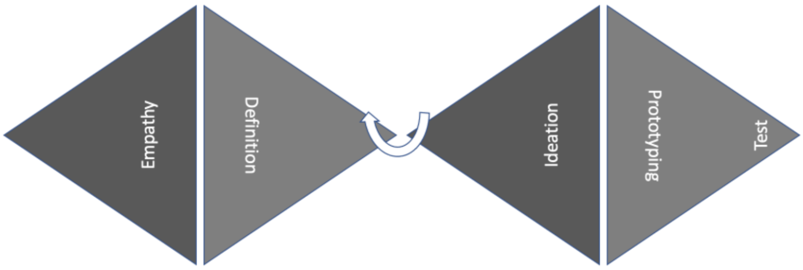

Fig. 3. Design thinking approach (Clune et al., 2014)

The term "Design Thinking" first appeared in 1987 in a book published by Rowe [25]. It is a design method that focuses on innovation and people. This method is very much linked to user experience because its objective is to develop a product with a design that solves the users' problems and corresponds to them [24]. With the Design Thinking methodology, design is not done randomly or according to ideas. It is made for the users and according to them.

In this section, we will detail the methodology we used to design the Learning game based on the Design Thinking methodology. Following this methodology, we used 5 steps that are listed below:

- Empathy phase
- Definition phase
- Ideation phase
- Prototyping phase
- Test phase

4.1 Empathy phase

First, during the empathy step, we established the state of the art that we presented in the previous section to understand what was already done for digital Learning game for learning and to understand in which area we should focus on. Then, we made a benchmark of existing digital games to identify which type of game would be the most appropriate for the Learning game. For this benchmark, we tried 20 games that we selected among top games from the AppStore and Google PlayStore. The games were tested during a session of 10 minutes by two engineering students, and a 55-year-old teacher. They had to evaluate the originality of the game based on three criteria: the fun they had playing the game, the number of interactions they had with the game and the original features of the gameplay. They also had to evaluate the suitability of the games for every age based on three criteria: the understandability of the game, the difficulty of the scheme that needs to be integrated by the player and the timelessness of the game. For example, concerning the game "Chess", for the originality, in average, participants gave 9/10 for the fun, 9/10 for the number of interactions they had with the game and 9/10 for the original features of the gameplay. Thus, "Chess" has an average score of 9/10 for the originality. For the suitability, the average scores are: 9/10 for the understandability, 8/10 for the difficulty of the scheme and 10/10 for the timelessness of the game. That gives "Chess" a suitability score of 9/10.

We established, from the test we made, the graph in Figure 4, representing the distribution of the game according to their originality and suitability for every age scores.

Fig. 4. Benchmark of digital smartphone games

From this benchmark, we find that the games are divided into three different areas: games that are very original but not suitable for all ages, games that are very suitable for all ages but not original and finally games that are original and suitable for all ages.

Given that the public we target with the Learning game is aged between 30 and 60 and does not have strong familiarity with video games, we need to get inspired from games that are highly suitable for every age.

To distribute the game as widely as possible, we design it to be playable on smartphones. Therefore, to get inspired, from the benchmark presented in Figure 4. We identified 4 categories of digital games on smartphone: games adapted from board games, games adapted from computer and console, arcade games and digital support for non-virtual games.

Fig. 5. Categories of digital smartphone games

The first category presents games that are based on board games rules but playable on smartphones. Most of the time these games present features that cannot exist on physical board games such as online ranking, challenges, or tutorials.

The second category is games adapted from computer or console games. The main difference between the app and the original game is the controller. When for console and computer, there is an external controller such as a gamepad or a keyboard, smartphone games are controlled directly from the screen. Thus, the mechanics of gameplay need to be reworked to fit with this kind of controller. Also, the size of the screen can have an impact on the game.

The third category is arcade games. This category includes games that are played for a brief time, are very repetitive and do not contain a narrative element. The game mechanics are often quick to learn. These games contain a scoreboard that tells the player his score and the best score to beat to surpass himself.

The last category includes games that are used as support for non-virtual games. These games can replace cards, game master or hourglass. It also can use technologies as augmented reality to mix real life and virtual world.

According to Clark et al. (2011), when the user focuses too much on playing, the learning potential is greatly reduced. Thus, we have chosen to develop a game with simple mechanics that require the player to analyze information before acting. Based on the 4 categories that we have stated, the type of game the most adapted to our problem is Arcade Game [19].

4.2 Definition phase

Based on the previous decision to develop an Arcade Game, we created the specification bills of the game. We have defined 10 functions that the game will have to satisfy. These functions are related to the technical aspect of the game, the intellectual property, the gameplay, and the learning content.

These 10 functions are listed below:

- The game must allow the participants to learn the opportunities and examples of AM.
- The game must be playable on any smartphone or tablet
- Users must be able to play the Learning game autonomously
- The game must be replayable by the same player
- The game must remain up to date with the technological advances in additive manufacturing
- The game must be protected from hackers
- The game must respect patents, copyrights, and other regulations on data sharing
- Players can compete with other players
- Players can record their learning progress
- The difficulty of the game must increase over time

The definition of the need to which the digital learning game must respond has allowed us to clearly identify the functions that we will have to think about when designing it. This will allow us to focus our ideation phase on concepts that will meet our expectations.

4.3 Ideation phase

After defining the expectations of the learning game, we sought to generate game concepts that would meet them. For this, we used concept generation methods based on the principle of group creativity sessions. According Balakrishnan et al. (2021), "Creativity is a process of generating new, novel ideas that could solve problems or address issues" [24]. So, we organized a session to generate concepts. For that, we selected four engineers and one product designer who are interested in video games. One of the participants had no interest in video games, so they have ideas less inspired by the existing. The session lasted three and a half hours. During this session, we used tools such as brainstorming, purge, inversion, constraint matrix and inspiring mood board.

Figure 6 presents the creativity session proceedings. The first step of the session was a presentation of the subject, an explanation of the objective and a presentation of the board game that we are inspired by. The second step is an Ice Breaker, which has the purpose of making participants comfortable. Then, we did a brainstorming phase using purge methodology. The purge consists in making the participants express everything that goes through their mind concerning a subject (here the mobile games). The next step was also a brainstorming phase using the inversion methodology. This method allows participants to create the worst ideas so they can avoid them in the future step of design. Then, participants generated concepts of serious games and presented them to the other participants to improve each concept. Finally, the concepts were formalized into an idea sheet.

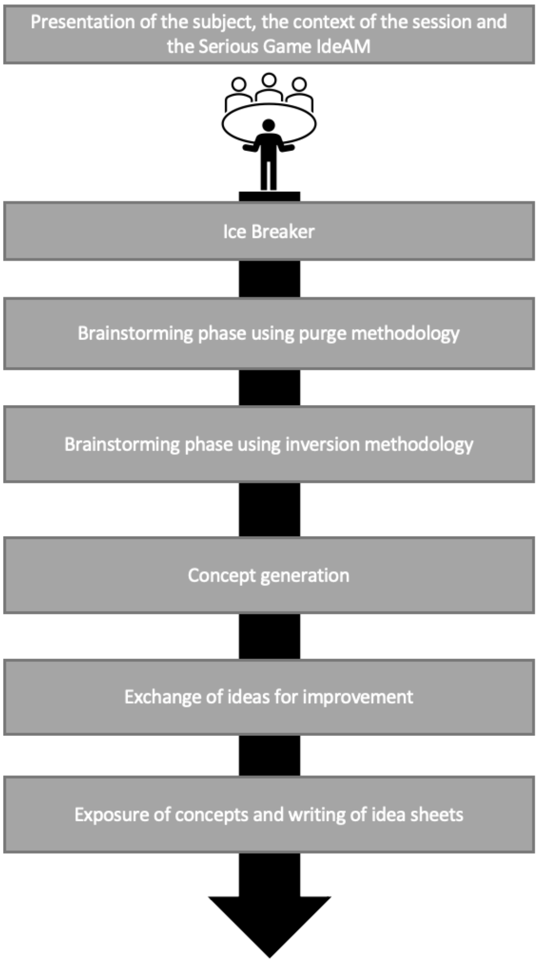

Fig. 6. Creativity session proceedings

From this session we generated 9 concepts of learning games that could respond to the specification bills that we established. We then evaluated these concepts with the participants according to the following criteria: feasibility, respect of the specifications, adapted to all ages and originality. The concept that has been retained will be presented in the following section. We named it "IdeAM Running Quiz".

4.4 Prototyping and testing phases

Unity3D is a free game engine developed by Unity Technologies company. Game engines are used to make games. It enables programmers to create 3D and 2D environments and to create scripts that make elements of the game interact with each other and with the player [27]. Unity3D game engine is one of the most used programs today

[28]. It enables developers to create game supported by PC, MAC, Linux, Android, iOS, XBOX 360 and PS3. Unit3D offers the possibility to code in JavaScript, C # and Boo languages.

For our project, we are using C# as the working environment. The 3D items used for the environment are provided in the Unity Library and we import the 14 opportunity cubes as .obj 3D object.

Our game takes place in several scenes, each of the scenes being linked together by scripts that are triggered when the player interacts with the game.

Once the prototype has been made, we conducted an experiment to evaluate the effectiveness of the game. The platform used to test the game was a smartphone. The experiment protocol and the results are respectively presented in part 6 and 7.

5 Description of IdeAM Running Quiz

IdeAM Running Quiz is a smartphone application with two aspects. The players can review the opportunities of additive manufacturing through cards in the "review opportunities" section. They will then be able to test their knowledge in the "play" section that we will describe in the following. The interface of IdeAM Running Quiz is presented in Figure 7.

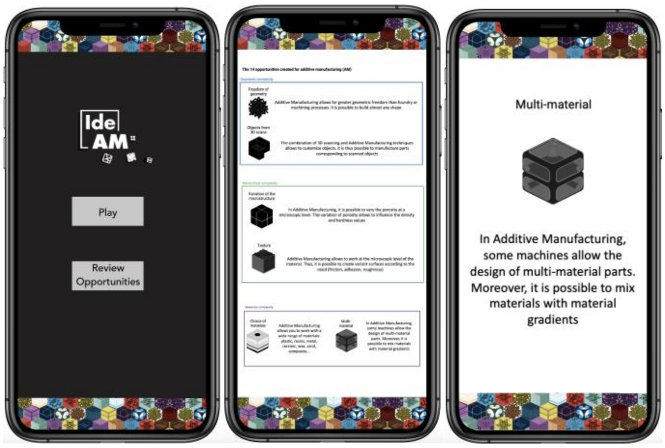

Fig. 7. IdeAM Running Quiz interface

In IdeAM Running Quiz, the player will play a character that has to run onto an endless track and will have to choose the good path among three paths. The three paths correspond to three AM opportunities represented by different cubes. Every time players will have to make a choice; they will see at the top of their screen an object that corresponds to something that can be done using a specific AM opportunity. Thus, the player will have to choose the path that corresponds to the opportunity that matches with the example on the top of the screen. When the players fail to choose the good path, an explanation will be provided to help them to understand their mistake. This explanation takes the form of a card containing the following information: the answer that should have been chosen and an example corresponding to the answer chosen by the player.

Figures 8 and 9 show respectively the Unity environment where we developed the game and an in-game example of match between a cube and an example. A possible scenario of game play is presented in Figure 10.

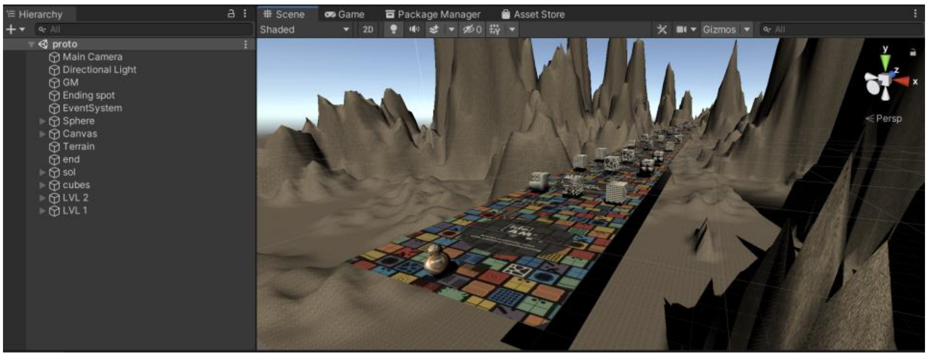

Fig. 8. Prototyping of IdeAM Running Quiz on Unity

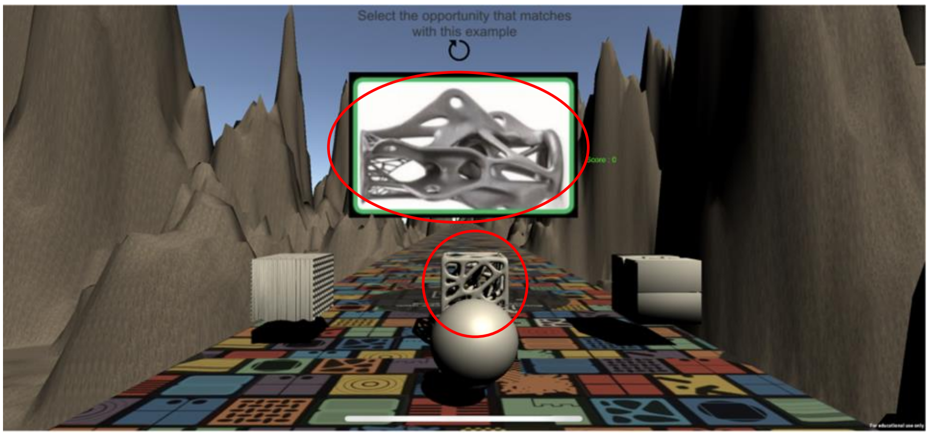

Fig. 9. Example of correspondence between example card and opportunity cube

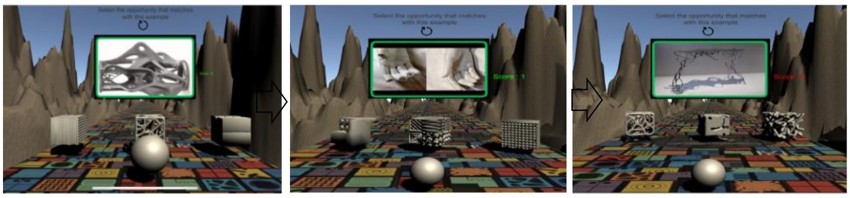

Fig. 10. Scenario of gameplay

In the scenario presented in Figure 10, players must choose a path for the first example that is shown. Here, they choose the center way which is the right way. Thus, the score increases, and another example is presented. The players choose the center way again, which is not the right way. Thus, the score decreases, and another example is presented. The game will go on since the player has experimented every possible example.

We chose to use Science Fiction graphical identity. Using this type of universe within a corporate project has several advantages such as encouraging divergent thinking and allowing the player to create his own universe which will help the memorizing. After prototyping the game, we test it as described by the protocol presented in Section 6.

6 Testing protocol

In order to test the game, we use the following protocol presented in Figure 9.

As presented in Figure 11, participants complete a questionnaire on AM a first time to assess their initial knowledge of AM. Then, they play IdeAM Running Quiz on a smartphone. They can take the time they need to play and review the AM opportunities. Finally, they complete a second time the questionnaire to assess the evolution of their knowledge of AM. In the second questionnaire, participants also answer questions about their feelings about the game.

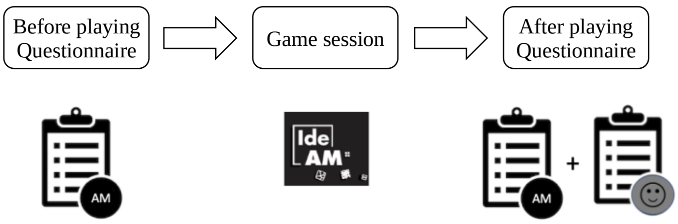

Fig. 11. Testing protocol with questionnaire about AM knowledge and questionnaire about participant's feeling

We asked participants, before and after they play the game, five questions about their perceptions of the four complexities of AM (Geometric (GC), Hierarchical (HC), Material (HC) and Functional (FC)) using the following Likert scale: zero : Totally disagree, one: Disagree, two: Somewhat disagree, three: Somewhat agree, four: agree, five: Totally agree (Table 1).

Table 1. Evaluation grid for knowledge about AM related to GC

Geometrical complexity (GC)	Totally disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Totally agree
Q1- I feel able to explain the opportunities of AM under the GC to someone else						
Q2 - I feel able to give examples of objects that take advantage of AM opportunities that are relevant to GC						
Q3 - I feel capable of proposing ideas of innovative object exploiting the opportunities of the AM relevant to GC						
Q4 - I feel able to recognize objects exploiting the AM opportunities related to GC						
Q5 - I think I have mastered the AM opportunities related to CG						

After participants play the game, we also evaluate their feelings to know if they took pleasure and were entertained while playing (Table 2).

Table 2. Evaluation grid for participant's feeling

Feelings about the game	Totally disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Totally agree
I enjoyed playing IdeAM Running Quiz						
I want to play IdeAM Running Quiz again						
I think that the IdeAM Running Quiz is an appropriate medium to disseminate information about the opportunities of Additive Manufacturing						
I would recommend IdeAM Running Quiz to someone who wants to discover the opportunities of Additive Manufacturing						

Through this methodology, we will evaluate the evolution of the perception of the participants regarding the game and their knowledge about AM opportunities after playing IdeAM Running Quiz.

7 Results

To evaluate the effectiveness of IdeAM Running Quiz, we conducted an experiment on 11 participants. The panel of participants consisted of two young professionals, one design student, six engineering students and two retired people. Participants were aged between 23 and 67 years old.

Each participant answers the questions with the Likert scale described in the previous section (0 to 5 point). Thus, we can measure the evolution of the participants' perception of their knowledge.

7.1 Evaluation of the effectiveness of IdeAM Running Quiz on participants' knowledge

Figure 12 presents the results of evaluation grid for knowledge about AM related to the four complexities of AM: Geometric (GC), Hierarchical (HC), Material (MC) and Functional (FC).

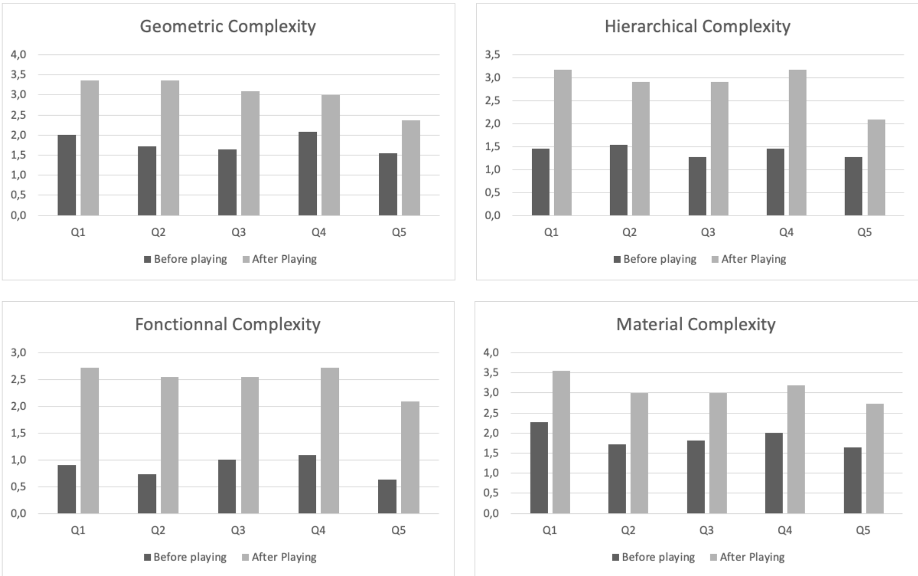

Fig. 12. Evolution of participants perception for each complexity

Results presented in Figure 12 highlight that IdeAM Running Quiz is more efficient for functional complexity and hierarchic complexity. Indeed, before playing the game, the average score of participants' perceptions of their knowledge about the functional complexity was 0.9/5 while this score reached 2.5/5 after playing the game. For the hierarchic complexity, the average score of participants' perceptions of their knowledge went from 1.4/5 to 2.9/5. The efficiency of the game is very satisfactory for these two complexities, although the knowledge learned by the participants during the game does not allow them to reach a total ease towards these complexities.

Although the evolution of the participants' perception of geometric complexity and material complexity is lower than for the two previous ones, it remains satisfactory. Moreover, the overall understanding of these two complexities is better than for the two previous ones at the end of the game session. Indeed, the average score of participants' perceptions of their knowledge reach 3/5 for these two complexities.

7.2 Evaluation of participants' feelings

Figure 13 shows the evolution of participants felling about their knowledge before and after playing IdeAM Running Quiz.

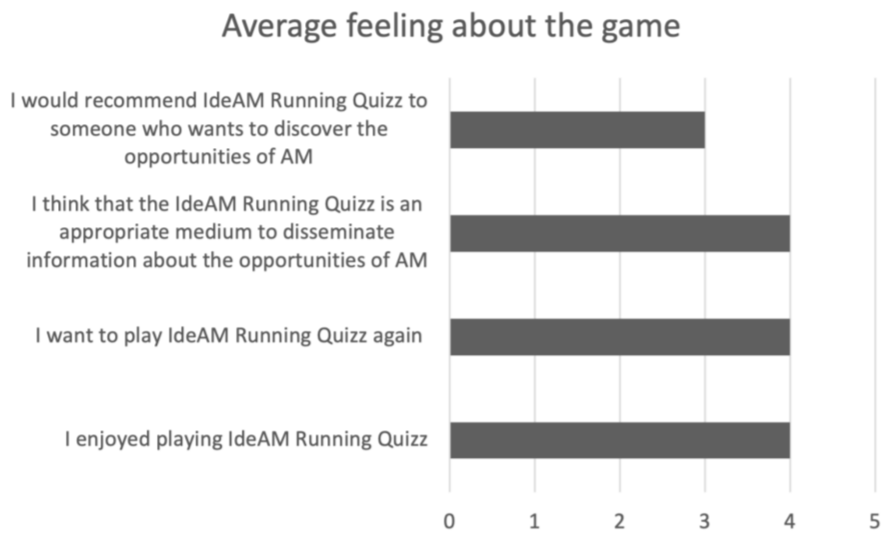

Fig. 13. Average participant feeling about the game

We can see that in average, participants enjoyed playing IdeAM Running Quiz and would play it again. Even if entertainment is not the main purpose of a learning game, players should have fun while playing. Thus, our first test phase shows us satisfactory results when it comes to the pleasure of the players playing. Indeed, in average, participants agree with the idea of playing IdeAM Running Quiz again, they also agree with the fact that they enjoyed playing IdeAM Running Quiz. Finally, participants agree with the idea that IdeAM Running Quiz is an appropriate medium to disseminate information about the AM opportunities.

8 Conclusion and perspectives

After presenting a review of literature about Design and Additive Manufacturing and Digital Learning game, the article describes the steps involved in creating IdeAM Running Quiz: a learning game for additive creativity, as well as method for evaluating the game for improvement during its design. A first test phase has been done to evaluate the effectiveness of the game on immediate learning of the Additive Manufacturing opportunities and to evaluate how much participant like to play IdeAM Running Quiz. The test conducted shows encouraging results as the participants' perceptions of their knowledge about AM opportunities have significantly grown for every complexity of additive manufacturing. Moreover, participants of the experiment all agree that IdeAM Running Quiz is fun to play and that it is appropriate for AM knowledge dissemination.

Further work will focus on the implementation of ranking and multiplayer system in IdeAM Running Quiz to add motivational aspect in the game. As the learning game is intended to be used in an industrial environment by professionals in the 30-60 age group, it will be necessary to reiterate the tests to evaluate the potential learning differences according to the age of the users. The influence of playing the game several times with different scenarios should also be tested. When these tasks will be done, we plan to upload IdeAM Running Quiz on mobile application platforms. We believe it will help professionals to enhance the discovery of opportunities in Additive Manufacturing to optimize their product design.

Finally, further work could focus on the use of other types of objects, such as digital objects, videos, or other physical objects, in serious games for learning in Additive Manufacturing.

9 Acknowledgments

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