Chapter 1
Game-Based Learning and Assessment of Creative Challenges Through Artefact Development

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Introduction

The future of quality education with a high skills training value must be student-centred with an intelligent and multidisciplinary educational system supported by adaptive learning programmes, collaborative methodologies, digital learning resources and STEAM technology training and adapted to Industry 4.0 (Uskov et al., 2018). It must also improve creativity, the visibility of learning outcomes and communication, motivation and interest in learning. The educational environment applied by smart pedagogy must develop skills of a technological-pedagogical nature and predictive analytical skills to develop an educational environment and an intelligent society (Daniela, 2020). These educational environments must be flexible and capable of integrating new forms of learning, such as learning by doing, project-based learning, module-based learning (López-Forniés et al., 2012) or others that promote "active learning" and focus on experiments carried out by students, whose results indicate their learning (BenMahmoud-Jouini & Midler, 2020).

The game-learning relation, and the use of games as a vehicle for learning, has long since been of interest for educators (Chmiel, 2019). Learning theories of socio-cultural cognition or learning theories indicate that potential games have to motivate, engage and provide real learning experiences. The integration of game into learning is justified by it involving game elements, such as incentive systems, to motivate players to engage in tasks that they otherwise would not find (Plass et al., 2015). In addition, the learning experience with game favours knowledge retention as emotion is an element that favours cognitive processes, such as memory. Wouters

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L. Daniela (ed.), *Smart Pedagogy of Game-based Learning*, Advances in Game-Based Learning, https://doi.org/10.1007/978-3-030-76986-4_1

et al. (2013) show that, according to a set of reviewed studies, games are more effective in learning and retention terms than conventional instructional methods.

Playful and creative activities share certain characteristics that remind us of a direct relation, which are often intrinsically motivated and almost never occur when participants are anxious or they focus on achieving a specific goal (Dansky, 2011). Both involve transformations, possibilities and unusual combinations of ideas, actions and situations.

Integrating games into product design and creativity activities requires a specific definition of learning objectives and custom design because the design process of games for learning involves balancing the need to cover the subject matter and the desire to prioritise game play (Plass et al., 2015). Play in learning also develops twenty-first-century skills, which are very valuable in future designers, such as teamwork, collaboration, co-creation, problem-solving, creativity or communication (Plass et al., 2014). Design challenges as games can be played in groups and involve meeting and coordinating with one another and competing as teams. Product design also involves creative problem-solving work and sometimes the construction of a prototype that effectively represents and communicates the solution designed to compete in the game.

By separating assessments from learning, fun leads to a free-thinking situation, and the academic result objective becomes a new objective as points, best times, best performance, a record to beat, etc. The legislative thinking style (Sternberg, 2010), oriented to tasks, projects and situations that require creation, formulation and planning ideas, strategies, products and the like (Sternberg, 2020), positively and directly influences metacognitive strategies that impact creative production (Gutierrez-Braojos et al., 2013) and can be considered an intellectual style that facilitates the definition and redefinition of problems. Achieving this free thinking is possible, thanks to the integration of legislative thinking and game elements into creative thinking. Game elements can be affectively related to interest, motivation and training in values or to elements of character that promote discipline, tenacity and audacity (Burgos et al., 2010).

Tim Brown (2008), designer and CEO of the IDEO company, expresses the idea that design, game and prototyping are related. He believes that play helps to come up with more creative solutions and make a better design and helps to feel better when working. Prototypes allow you to play and "think with your hands" so you can quickly perform many tests with low-fidelity prototypes.

A proof of concept (POC) shows that a product or feature can be developed, while a prototype reveals how it is developed. A POC is designed purely to verify the functionality of either a single concept or set of concepts to be unified in other systems (Singaram & Prathistha, 2018). The POC is a way to move away from uncertainty. Although it does not offer a final solution, it demonstrates that the idea works, and the first results confer us confidence in knowing what the final design process requires (Cohen et al., 2015). Sometimes the word prototype is more colloquial and easier to understand by nonexperts, although the term artefact is used in this chapter to refer to the presented cases that came closer to a POC.

The artefact or prototype is a learning tool and represents an idea through which concepts can be discussed, changed and negotiated (Rodriguez-Calero et al., 2020). It implies players designing and building their game tools, which also happens in fighting robot competitions for learning robotic vision (Culler & Long, 2016), in truck design challenges to apply physics concepts while testing the use of bearings (Aguilar Martín & Santo Domingo, 2018), in paper plane competitions to learn statistics (Ruiz Sánchez, 2020) or for understanding fluid dynamics processes (RedBull, 2018). In contests, the artefact acts as an editable model (Lennings et al., 2000) that is iteratively adjusted and leads to learning about optimisation and improved performance.

To win or lose, which fall in line with follower robot races (OSHWDem, 2019), depends on the effectiveness of the prototype, the improvement and the adjustment based on the tests carried out and also the participants' training and skills. The starting conditions are the same for everyone and what is shared is an open-source code for learning to programme. Game-based learning provides a safe place in which to fail and learn, challenges students and provides immediate feedback, including socialisation as an additional stimulus (Hertz, 2013).

In creativity assessments, several metrics are used and refer to generic dimensions, such as novelty, usefulness, feasibility and the like (Shah et al., 2003; Dean et al., 2006; Kudrowitz & Wallace, 2013). However in game-based learning, it is more logical to assess creativity by evidence-centred design (Mislevy et al., 2003; Zhao et al., 2015) and to validate the creative solution. The dimensions measured by the metrics allow game results to be compared and goal achievement to be evaluated.

As some terms are confused, such as gamification, game-based learning and serious games, we point out that gamification refers to the use of game elements and serious games use games to motivate learning (Tecnológico de Monterrey, 2016). The choice of game-based learning for the experiments presented in this chapter is linked with the objectives of the learning outcomes in creativity, problem-solving by applying creativity to interpret the problem and to generate solutions, learning through construction, improvement and adjustment of an artefact and competition according to rules and limitations, to verify the effectiveness of the design in relation to other similar or different solutions.

Creativity Challenges: Three Experiments for Applying Creativity and Artefact Building

According to the definition of Chmiel (2019), game is a form of entertainment that is limited by rules, often competitive ones, and is based on some kind of skill. In games, participants can propose strategies and tactics that adjust to the mechanics of the game, and rule-based systems are designed to govern the mechanics and limit actions in a game. Two of the experiments we present herein are based on competitive game activity using an artefact as a game tool to achieve certain goals that conform to rules, the challenge and learning feedback (Roungas & Dalpiaz, 2015). The third one includes neither a game nor competition, but involves the same learning objectives as the picking up balls (PUB) one and serves as a reference for comparison purposes. The experiments involved different groups of students according to the number of components and the required design.

Three experiments are presented, each with a challenge to overcome that involves learning creativity being applied to product design as part of the Degree of Engineering in Industrial Design and Product Development. This creativity is expressed by constructing an artefact that solves a problem or meets set goals. Experiments were similar for integrating the following factors, creativity, problem-solving and constructing an artefact, but had different goals and conditions. To integrate game and the playful aspect, two of the cases are presented as competitions to engage all the participants in the shared fun and in observing work and the other participants' achievements. The third experiment proposes a challenge based on goals to compare the results.

The participants must face challenges as a creative process applied to a design problem by fully defining their own objectives, difficulties and limitations. They also generate ideas and seek solutions to the problem by sketching representations before moving on to construct an artefact and its test operation to achieve goals, and all this during an iterative process of optimisation cycles (Lennings et al., 2000).

The first experiment forms part of the optional bio-inspired design subject with 22 participants. The initiative came about at the students' request who, after completing the teaching activities, asked to undertake a quick competition project on 1 day for the sheer fun of it and to have a good time with their classmates by applying the knowledge they had acquired. Participation was open to the other students who do not study this subject to form groups made up of up to four people. Figure 1.1 shows the poster announcing the bionic design challenge (BDC) with the contest

Fig. 1.1 The bionic design challenge poster

bases, which stressed that the brief project was a surprise. The goal was to design a helmet or protective headpiece with no specific application, but it had to withstand heavy blows, and involved holding a fragile object to be protected, simulated with a balloon filled with water that weighed 1 kg. The impact test was carried out by throwing the helmet with the balloon inside from a tower with a free 12-meter fall. Several designs were assessed, such as inspiration in nature, feasibility, aesthetics or the fun aspects of the design and presentation. With this exercise, concepts about energy absorption and dissipation, damping, programmed breakage, light structures, resistance of materials, etc. are learned. On the Biomimicry Institute website (AskNature.org, 2017), the participants can consult the functional taxonomy, where they can search for functions and references in nature to find solutions by analogy.

During the second experiment, called picking up balls (PUB), an artefact had to be designed to collect balls during a time trial competition. Before the participants started their project, a series of YouTube videos were shown about how to make homemade traps to catch rats with recycled materials by applying very basic principles of physics, but filled with creative thinking. These videos (Imaginative Guy, 2018) aim to stimulate creativity and ingenuity and to help students to perceive how easy it is to make an effective trap with very few recycled materials by simply applying creative thinking. Another objective was for them to perceive the potential of constructing and testing artefacts so they could start the trial-and-error methodology by making improvements to their artefacts and correcting both experimentation and observation (Brown, 2008). The challenge lies in designing and building an artefact that allows balls or marbles to be collected to simulate a particle system in a limited space. Students practice with physical concepts and material characteristics, such as stiffness, flexibility, deformation, thrust, friction, etc. They must also develop a certain skill in handling artefacts, which means that the design is conditioned by the effective and efficient use in relation to a given time.

The goal of the third experiment is to design and build a tape dispenser (TD) and includes the function of measuring the amount of cut tape. A series of limitations is included in the brief design that corresponds to the objectives to be academically evaluated, e.g. ease of use, measurement accuracy, a clean safe cut and the number of pieces or quantity of materials used. The design must also present some improvement to existing dispensers on the market to evidence the application of creativity to the design process. During this exercise, creativity concepts are learned about generating functional alternatives in both cut and size, optimising resources and adaptation to use. Establishing each goal is a problem to be solved and must be integrated into a single device. As some goals can be antagonistic, students must apply their ingenuity to integrate and overcome them in a balanced manner. They also learn by building; by observing the viability, feasibility and operability of their prototype; and by correcting concepts or construction errors. This type of project has been proposed in other academic years given the learning objective of maximising or minimising a function, as in building toothpaste dispensers to regulating doses, citrus fruit squeezers to facilitate cleaning, rice dispensers to measure doses within a variable range, etc.

With learning experiences through play, a series of essential components is structured (Fullerton, 2014), such as players, goals, rules, resources, conflicts, limitations and results. Table 1.1 shows these essential components for each challenge, which make competition fair under equal conditions. All the experiences were designed for learning and difficulty levels according to everyone's knowledge and skills. They required a medium level of active participation and the time spent was quantified.

The objectives of each challenge were adapted to the knowledge type that had to be learned with the subject, but by highlighting some points that made participation more challenging and fun. Rules were defined to confer the group homogeneity and equality, as were available resources to avoid external advantages to creative contribution and the participants' skills.

In both BDC (helmet) and PUB, which involve play and competition, conflict and rivalry to help to obtain the best mark, there were no winners or losers. However, rivalry was generated at the time of participation given the desire to win or exceed a partner's mark. The game limitations were, on the one hand, physical, namely, the structure where balls were collected, the collection area, height of walls, etc., and, on the other hand, they involved material resources and time which, for the participants, were their own design space limits (López-Forniés, 2021). The results were uncertain and uneven. With BDC, players only had one chance because there was no time or materials to carry out previous tests, and a second try would generate uncertainty as to whether the design would withstand impacts. Moreover, the chosen design and its construction marked differences in the participants. Success or failure in achieving the goal was the proposed challenge, instead of winning or losing, and the results were unknown when the game began. Uncertainty generated some stress in those who had still not participated given the possibility of losing a mark or having the chance to do better than those who had already burst their water balloon. It was only at the end of challenges when results were clarified and stress disappeared.

The first two experiments took game into account, and both included an element of challenge, fun and playful learning. Game mechanics differed because, when collecting balls, solutions could be established tactically to obtain a better result. For example, differences are marked between designs to collect balls one by one, done in small groups, large groups or all at once. It is even than game sport played in a field because it had rules and scoring linked with the number of collected balls and spent time. However, there were no defined game mechanics in BDC and only one chance, namely, a single launch, because no previous launches from the tower were allowed. The helmet design included two intermediate presentations: the concept to be developed and prototype construction. In both cases, corrections and suggestions were made by the teacher to reinforce ideas and to learn from them.

Another difference lays in incentive, and the only motivational element in BDC was the prestige of passing the test as rewards only took a symbolic value. PUB included a score and a classification, which form parted of the final course mark. Training and practicing the test beforehand were allowed to determine which of the two components of the pair was more skilful or faster and to choose the participants for the day of the competition.

The reward in the first experiment was participating, although some trophies were designed and six categories were established. Trophies were made from recycled material and were distinguished by colours (see Fig. 1.2). Each colour corresponded to a category, the most resistant one to pass the balloon breakage test, the

Table 1.1 Challenges for experimenting with artefacts through creative design-based games

Game element	Bionic design challenge (BDC)	Picking up balls (PUB)	Tape dispenser (TD)
GBL	Yes	Yes	No
Participants	22 participants from years 3 and 4 of the Degree in Design Engineering. Seven groups with up to four members are formed	73 students of year 2 of the Degree in Industrial Design Engineering. Participation is in pairs or as individual, as preferred. There is only one try	79 students in year 2 of the Degree in Industrial Design Engineering. Participation is individual
Goals Objectives	Prevent water balloon from (1) coming out of the helmet while falling and after impact and (2) breaking after hitting the ground. (3) Minimise the use of material. (4) Aesthetics and constructive evaluations	Collect as many balls as possible with diameters of 16 and 25 mm. Collect all 50 balls in the shortest time possible (15 large, 35 small). Minimise parts and material usage	There are four goals (measure, cut, facilitate, economise). Dispense masking tape by measuring the length before making a clean safe cut, easy to use with the fewest pieces or the least material
Rules	The biomimetic relation must be justified. Manufacturing the prototype must be done manually or with hand tools. Launching from a tower at a height of 12 m	First round limited to 30″ to count the number of balls. Second round continues to 5′. Balls must be collected in a defined area inside a square ring in order to be valid	The prototype must be built manually or with hand tools. 3D printing or rapid prototyping machines are not allowed. A fail mark or a zero score is allowed only in one goal
Resources	Limited to the materials delivered to teams. All the materials are waste that have been recycled and cost €0. Time is limited to the competition time, from 9 am to 3 pm	Limited to recycled and recovered materials. All the materials are waste that have been recycled and cost €0. The project time for designs and prototypes is 4 weeks	Save the number of parts and material used. Use materials recycled or recovered from other products. The whole exercise lasts 4 weeks
Conflict Rivalry	There is no direct rivalry, but is a matter of achieving goals. There is no conflict, and a good atmosphere must be perceived during the competition	There is no direct rivalry while designing and constructing the artefact. There is rivalry at the time of the competition. There is no conflict	There is no direct rivalry with other participants, because it is about overcoming the goal individually. There is no conflict

(continued)

Table 1.1 (continued)

Game element	Bionic design challenge (BDC)	Picking up balls (PUB)	Tape dispenser (TD)
Limitations	Time and materials are limited. Purchasing parts or materials is not allowed. Recycled materials found in the university can be used	The operation must be exclusively manual and mechanical. Motors or electrical devices are not allowed. Suction systems cannot be used. The device can only be operated by one person and by one hand	There is only one limitation with materials. Buying or using parts or components from other dispensers is not allowed. The students are allowed enough time for their design and construction
Results Rewards	Launches are video-recorded and photographed. A poll is taken by the participants to deliver different prizes. The reward is fun and learning	According to the results, a table will be drawn with the distribution of times and the obtained mark. All the designs that collect balls in less than 5 minutes will pass the test and obtain a mark	Part of the mark is given depending on whether the learning objectives are achieved

Fig. 1.2 Symbolic awards and categories for the bionic design challenge

best design, the most viable design, the most aesthetic design and the most entertaining one, and, finally, there was a wooden spoon as a booby prize. Classifications were done by the participants voting. The organisers' opinions did not affect the results, which meant that selection was also a playful part of the game because organisers appreciated funny comments and jokes about designs and designers.

Assessing Creativity and Meeting Objectives

By taking a group of people and giving them a sheet of paper to make a paper plane with and offering them several launch opportunities to improve design and to verify which one flew the best, we establish competition, and we can subjectively state who the winner is. However, in order to be fair and be able to make a correct statement of who the winner is and to even make a classification, we must introduce some objective indicators, e.g. distance travelled, gliding time, height reached, not leaving the flight path, etc. With all these indicators, we can take accurate measurements to assess competitors' achievements by establishing categories by achievement, or using a combined classification of several indicators, which makes assessments a determining element of learning. So the participants must bear in mind that the assessment begins before the game, is applied while the game is underway and continues when the game has ended (Michael & Chen, 2005).

In order to compare the results of the three experiments, setting mechanisms for assessing or measuring the creative result formed part of the game design and served to check whether competing actually stimulated creativity. Fair play and equality had to be guaranteed with the game conditions, such as resources or time, so that the assessment only depended on the participants' learning, experimentation and the ability to combine knowledge, creativity and resources. The assessment also allowed to see if the construction of prototypes helped to improve or achieve better designs and if performance in the game was affected. During the game, obtaining a better result meant exceeding a minimum threshold and approaching the optimum of the set goals.

Classic metrics to assess creativity usually include the following dimensions: novel, useful and feasible (NUF) (Kudrowitz & Wallace, 2013). Other metrics were designed to measure and assess dimensions based on goal achievement (López-Forniés et al., 2017; Shute & Rahimi, 2021). In the three presented experiments, the creativity assessment was linked with the novel dimension, and the prototype assessment was linked with the useful and feasible dimensions, but goal-based metrics were also needed. Both kinds of metrics allowed the experiments in which the game forms part of the learning activity to be compared, for example, between the first and second experiments and the experiments that valued meeting certain goals thanks to prototype performance, as between the second and third experiments.

The basis for both metrics (NUF and goal-based) applied to the three experiments, as seen in Table 1.2, was the metric by (Kudrowitz & Wallace, 2013), in which each dimension was rated on a 3-point Likert scale (2 = yes, 1 = somewhat, 0 = no). Designs were independently assessed by teachers. The same range was used with a 3-point scale, but avoided the vague *somewhat* score, and each

Table 1.2 Creativity scoring rules (NUF and goal-based). Assessment conditions for each experiment

Dimension	Bionic design challenge (BDC)	Picking up balls (PUB)	Tape dispenser (TD)
(N) Novel	The concept is novel 1C and/or inspired in nature 2C	Original idea in group 1C and/or market 2C	Original idea in group 1C and/or market 2C
(U) Useful	After the integrity of balloon 1C and/or structure 2C remains	The artefact proves utility 1C and functionality 2C	The artefact proves utility 1C and functionality 2C
(F) Feasible	The artefact proves feasibility 1C and/or viability 2C	The artefact proves feasibility 1C and/or viability 2C	The artefact proves feasibility 1C and/or viability 2C
Goal 1	The artefact integrity remains #1, and the balloon is safe #2 after falling	The artefact picks up all the balls #1, and in less than 30 seconds #2	The artefact can measure #1 and is precise #2
Goal 2	The artefact is inspired in nature #1 and is well-founded #2	The artefact picks more than Qb_3 balls in 30 seconds #2, less than Qb_3 but more than Qb_1 #1, less than Qb_1 #0	The artefact can cut #1 and safety #2
Goal 3	The artefact is feasible #1 in a simple manner #2	The artefact picks the whole lot in less than Qs_1 seconds #2, more than Qs_1 but more than Qs_3 #1, more than Qs_1 #0	The artefact is easy #1 and intuitive #2 to operate (video evidence for number of operations)
Goal 4	The artefact is aesthetically pleasing #1 and related to nature #2	The artefact uses fewer than three components #2, uses three or four components #1, more than four #0	The artefact uses fewer than three components #1, and materials are recycled #2
Goal 5	The artefact #1 and the presentations #2 are humorous		

dimension was conditioned in such a way that if two conditions were met (in Tables 1.2 and 1.4 → 2C), the score was 2; if only one was met (in Tables 1.2 and 1.4 → 1C), the score was 1; and if none was met (in Tables 1.2 and 1.4 → 0C), there was no score. If the goal assessment met the main condition, it scored 1 (in Table 1.2 → #1); if it fulfilled it outstandingly compared to the other designs, it scored 2 (in Table 1.2 → #2); otherwise the score was 0.

From the novel dimension, two conditions were applied if it was more original than the participants' designs, and also in relation to the market or existing products, when it scored 2 points. If it only met one of the two conditions, it was scored 1 point, and 0 if it did not meet the two. The useful and feasible dimensions scored in the same way, with two conditions proven by prototype performance according to its operation and construction.

In the goal-based assessment applied in PUB, ranges were obtained thanks to quartiles, with a score of 2 when the assessed dimension was maximised Q_3 or minimised Q_1, with a score of 1 when it was halfway between quartiles Q_1 and Q_3 and with a score of 0 when the dimension to maximise was below Q_1 or above

Table 1.3 Polling by participants for the bionic design challenge

	Concept	Resistance	Bionics	Viability	Aesthetics	Fun	Total	%	Rank
G1 Herizont	Suricata	Fail	13	4	13	10	40	14,3	3
G2 Kiwi Peace	Cefalosaurus	Fail	–	–	14	23	37	13,2	4
G3 Rumanian	Armadillo	Fail	2	14	2	5	23	8,2	7
G4 Pulling Point	Armadillo	Pass	8	15	5	–	28	10,0	5
G5 Bushteam	Baby skull	Fail	25	26	1	2	54	19,3	2
G6 *Stegosaurus*	Kingfisher	Fail	7	3	5	12	27	9,6	6
G7 Bionic State	Grapefruit	Fail	15	8	30	18	71	25,4	1

Q_3 in the dimension to minimise. The goal-based assessment for the TD experiment was somewhat more subjective because it included no precise measures.

Only in the BDC experiment was the assessment open to the participants to encourage play and fun because it involved no evaluation or academic reward. Peer assessment-based game development also helped them to improve their in-depth thinking, creativity and learning motivation (Hwang et al., 2014). However, the organiser acted as an impartial judge to avoid irregularities that could favour or harm a group. Each group had 50 points, 10 points for each of the five categories. During the categories polling, each group had to distribute 10 points among the other groups and was able to award 10 points to one group and none to the rest. Polling was done secretly and then read aloud category by category. This polling system, like Eurovision (DitzyNizzy, 2021), means that the final part of the challenge is great fun and participants attempt to condition polling by showing certain dispute and ironical arguments. The summary of the votes from the seven groups is shown in Table 1.3.

Achievements and Interpreting Them

Artefact-based learning is a way to defend an idea and demonstrate how it works, which allows students and the teacher to discuss the design by reinforcement learning and improving the design from errors in the finished tests. The game also allows the inclusion of two factors of interest; the first is the stress or pressure generated by having to compete; even in challenges in which a record is set by an attempt (distance, time, tokens, points, etc.) for each artefact, in the end, a classification is generated in which the participants can see their rank, which shows the validity of their design, the success of the design decisions made in conceptual phases and their participation performance, which are transformed into academic marks. Secondly, there is the ludic and playful factor, which camouflages learning in the game. During the challenge, the participants forget about the academic component and focus on

Table 1.4 Summary of the results for the three experiments

	Bionic design challenge (BDC) (22 people, 7 cases)						Picking up balls (PUB) (73 people, 37 cases)						Tape dispenser (TD) (79 people/cases)					
	2C	%	1C	%	0C	%	2C	%	1C	%	0C	%	2C	%	1C	%	0C	%
Novel	Novel idea and based on nature						Original idea in the group and/or market						Original idea in the group and/or market					
	3	43	4	57	0	0	3	8	8	22	26	70	6	8	55	70	18	22
Useful	Balloon and structure integrity remain after impact						Artefact has proven utility and functionality						Artefact has proven utility and functionality					
	1	14	5	71	1	14	15	41	20	54	2	5	17	21	52	66	10	13
Feasible	Artefact has proven feasibility and concept viability						Artefact has proven feasibility and concept viability						Artefact has proven feasibility and concept viability					
	3	43	1	14	3	43	7	19	30	81	0	0	13	16	66	84	0	0
Goal 1	Higher impact resistance						Pick up the whole lot						Measure and/or precision					
	1	14	5	71	1	14	5	14	29	78	3	8	60	76	18	23	1	1
Goal 2	Best bionic design						Number of balls in 30”						Cut and/or safety					
	3	42	2	29	2	29	10	27	19	51	8	22	23	29	56	71	0	0
Goal 3	Most feasible						Time to pick up the whole lot						Easy and/or intuitive					
	3	42	1	16	3	42	9	24	19	51	9	24	44	56	35	44	0	0
Goal 4	Most aesthetic						Number of components						Minimum components and/or material					
	3	42	2	29	2	29	13	35	22	59	2	5	19	24	53	67	7	9
Goal 5	Offers the most fun																	
	3	42	2	29	2	29												

participating. This comes over more evidently in the BDC experiment than in the PUB competition where no academic assessment is linked with an academic mark, and the game is played on 1 day when everyone applies prior learning about design bionic, enjoys a good working environment and shares fun time.

One inconclusive aspect is that the process leads to artefact construction and its validation. In both the PUB competition and the TD experiment, the time allowed to build the artefact was about 4 weeks, during which time the participants had to propose conceptual solutions, make design decisions, build previous artefacts for testing, edit their designs to improve them and construct the artefact with which they had to achieve academic objectives and competition goals. Some of the participants made decisions quickly and failed, but had more options to learn from their mistakes and to stimulate creativity (Tahirsylaj, 2012). Others attempted different conceptual solutions to compare performance and to make decisions based on results and not on intuition. Artefacts helped to convert intuitive creative thinking into rational creative thinking so that imagined ideas could be validated by transforming them into something physical to be tested. The recommendation for the participants in the different experiments was to always seek alternatives and validate them with artefact tests. However, some participants risked everything with a single option. If the intuitive idea worked, they took it as being valid without further exploring it. So they opted for the first idea and ignored the critical learning process through failed attempts (Matson, 1996), which means that they had stopped learning this lesson.

From a qualitative perspective, it can be stated that the construction of artefacts was an academic objective achieved by all the participants and materialising the idea was, therefore, an achieved learning outcome. The level of finish, functionality and precision in performance vastly varied, but they were able to demonstrate what the presented idea contributed, its operation and feasibility, its number of components and its easy use.

Twenty-two students in seven groups participated in BDC, where the diversity of ideas and concepts was high, and were all inspired in nature. Only two groups chose the same living being to solve the helmet problem, but with different applications. However, their ideas were not entirely original as some concepts were based on precedents and application cases in marketed products or the scientific literature. All except one maintained helmet integrity after impact, and only one managed to prevent the balloon from bursting. The fact that there was only one attempt made it impossible to correct errors and improve artefacts, which rendered it very limiting in design improvement terms, but responded to limitations in a 6-hour competition. Three of the proposals could feasibly become products. However, three other proposals would prove very hard to develop due to lack of current technology. The learning achieved with these three proposals lay in the fact that, despite being able to build a prototype in an artisanal manner, reality ruled out its industrialisation potential. Figure 1.3 shows the artefacts made for launches. Pictures were taken during the second round, during a presentation before the final vote and the stress test.

Seventy-three people participated in PUB and made 37 artefacts. To analyse the creative dimension of novelty, 12 conceptual groups participated, of which 3 were unique in the group and presented state-of-the-art novelty. Eight of the other artefacts included in three conceptual groups presented minimum repetition, and two or three cases demonstrated novelty but were similar to one another. Finally for 26 cases in 6 conceptual groups, the creative contribution was poor because artefacts were similar and they repeated ideas that already exist in the state of the art, such as excavator shovels, norias, draft or drag shovels, fishing nets, pincers, tweezers, etc. Regarding usefulness and functionality, all the artefacts displayed the operation that was conceptually proposed, and only two artefacts broke during the competition from lack of trials. The participants had the opportunity to repair their artefact to compete again and obtain their mark. More doubts about feasibility arose, but the possibility of making the artefact was demonstrated, and only part of the artefacts made sense as products for collecting particles in a real environment. Those who thought about specific device applications came closer to viable products. Some applications had to do with rubbish collection on beaches and seabeds, games or toys with balls or sports applications. Other ideas about the collecting balls application were not developed to become a real product or an application for the market. Figure 1.4 shows the built artefacts. Models a, b, c and d operated similarly as they

Fig. 1.3 Presentation of helmets that participated in the challenge

were based on the deformation and plastic recovery of material, albeit in different configurations: mesh, in a point like a sphincter, aligned on a plane or aligned around an axis. Others were based on pushing, dragging, pinching or sliding (examples e–k).

The competition rules allowed varied concepts and different collection strategies, with a balance between speed and the amount of balls collected in each attempt. If winners achieved both goals, e.g. collect all the balls at once and in a record time of 13 seconds, it showed that the proposed creative solution enabled both goals to be achieved. In other cases, e.g. collecting in small groups, or one by one, had to be compensated by performing very fast actions during each attempt to prolong the total time. Figure 1.5 shows a design with a centrifugal operating principle that collected a few balls and the competition ring and the collection mark with the remaining balls after the first 30 seconds. Quick actions did not compensate the collection strategy in small groups.

Seventy-nine people participated in TD, each with their artefact. When analysing the creative dimension of novelty, only a few offered a differentiated contribution to the group and the market. Despite the fact that the added function of measuring was already something new, the presented measurement systems were not very original, but based on other measurement systems, such as tape measures, rulers, modules of pre-established distances, lap counters or cylinders with marks or numbers. Figure 1.6 depicts some examples. For utility and functionality, all the artefacts demonstrated the conceptually proposed operation. Artefacts' finish is an important

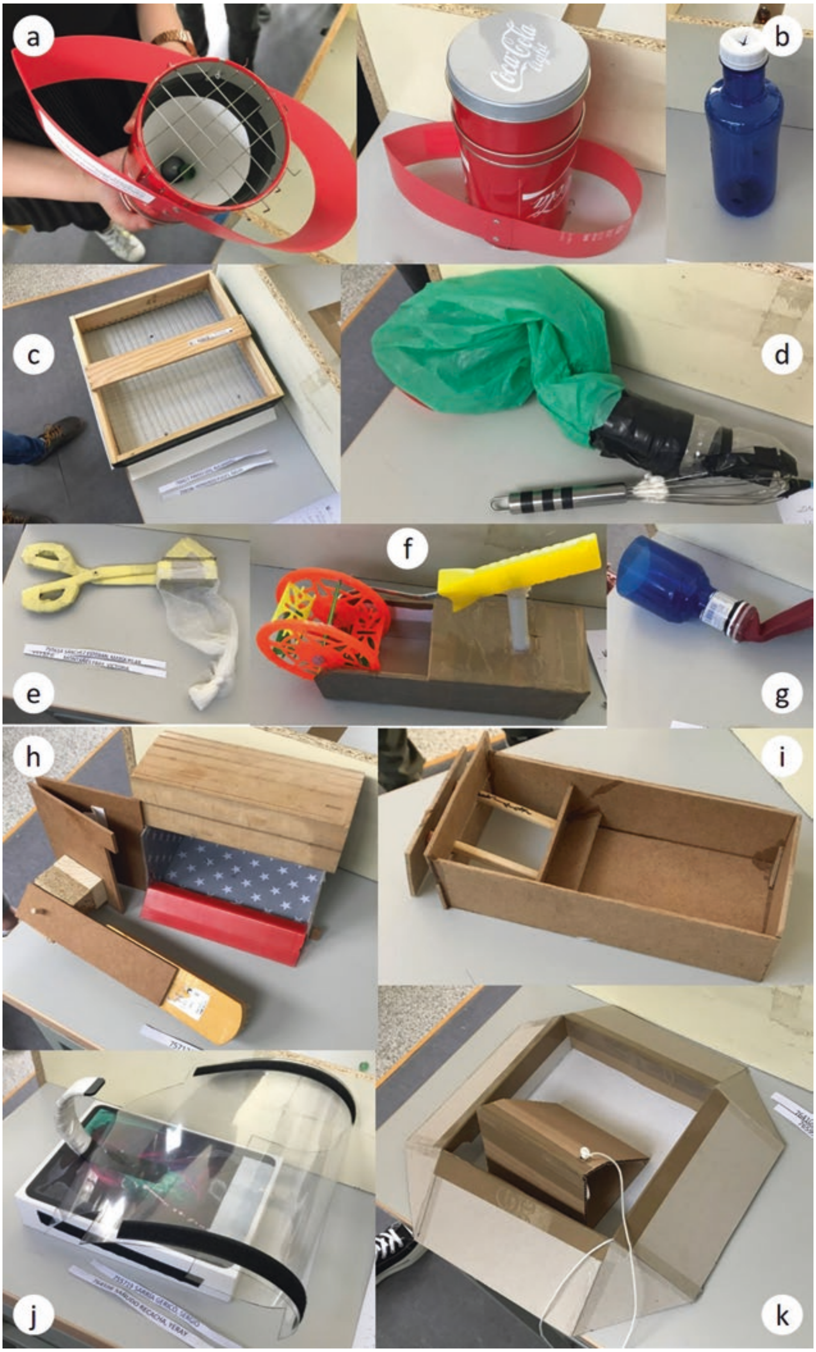

Fig. 1.4 Examples of artefacts built for the PUB competition

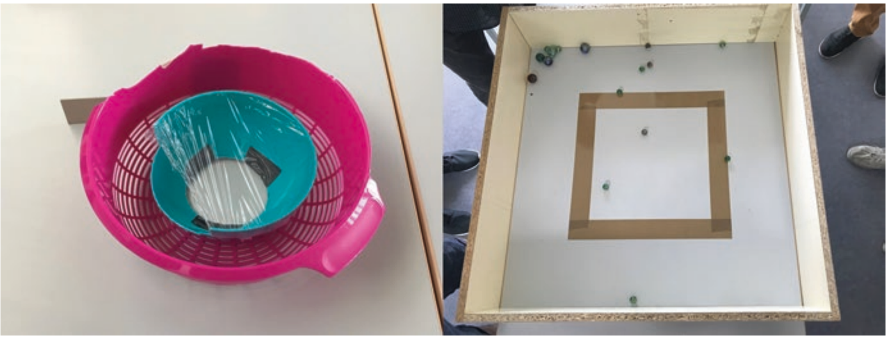

Fig. 1.5 Example of an artefact with centrifugal action and a competition ring with the collection area limits (brown lines)

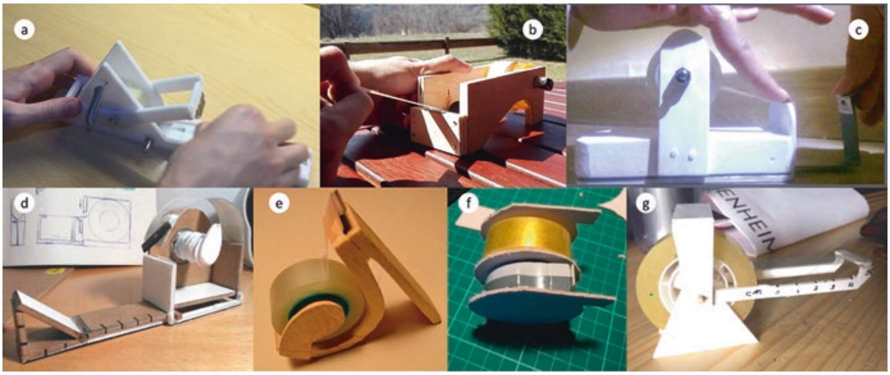

Fig. 1.6 Examples of TD artefacts showing hand use and different cutting systems

factor in the operation and there were problems while using some. Some designs were difficult to use because they required two-handed use or could be dangerous because of a cutting element being exposed. These factors were related to the goals of a second condition: obtain better results and provide feedback to the participants about improving their designs to develop real products. Regarding feasibility, once again they all demonstrated the possibility of building an artefact that worked, but only some could become viable products for the real market.

From a quantitative perspective, the following differences were observed in the experiments carried out, which are reflected in Table 1.4. Comparing the NUF metric to the goal-based one allowed a better assessment because goals were the determining factors of design or the game itself. The NUF dimensions should be restrictive and mandatory, at least for one of the conditions: assessing by means of the game's goals with measurable and quantifiable dimensions. Failure to meet at least one condition was a fail, the exercise had to be repeated and the participants learned from their mistakes. In PUB and TD, 70% and 22%, respectively, did not meet either of the two conditions for the novel dimension. This confirmed that only some solutions were genuinely original, 8% in both cases. For the useful and feasible dimensions, the compliance values were acceptable, but with low values for noncompliance under both conditions. These data indicate the need to make assessments according to the goals achieved in the game or competition, as long as the NUF minimums are met. This assessment would be fairer and allow a broader and more differentiated distribution of marks between the best and worst results.

The goal-based assessment carried out by the teacher in BDC was fairer than groups of students voting (Table 1.3). Some concepts were not scored on any dimension, and the difference between the best and worst was large and did not correspond to reality. Peer voting can be interesting to assess part of the project and to acknowledge classmates' work. Dialogue can also be established with which to make corrections that reinforce learning.

When comparing the PUB and TD experiments by goal achievement, it clearly came over that the results in TD were better because it was a matter of meeting a condition or not. So 0C percentages were very low, or even zero. However in PUB, the conditions that were more closely related to precise measurements (number of balls in 30″ and time to pick up the whole lot) led to higher 0C percentages compared to those dimensions with more elementary conditions (pick up the whole lot or the number of components). Using mathematical functions, such as quartiles, implied that the assessments with precise measurements better represented reality and allowed to adjust student assessments in an objective and measurable way. The only objection was where to set the threshold for each dimension to decide whether or not students had passed. It is also necessary to create custom metrics as each experiment differs and the metric to validate the metric's effectiveness must also be different (Takai et al., 2015).

Regarding students' academic results, there was no difference in the marks obtained in similar exercises performed in previous academic years, when game-based learning was not included. By comparing the PUB and TD marks, the average ones were 7.0 and 7.3, with maximums of 8.8 and 9.3 and minimums of 5.2 and 5.4, all respectively. Marks were slightly lower in PUB than in TD because the assessment was based on measurable and precisely quantifiable dimensions in relation to the condition-based assessment.

In other similar experiments to TD, more precise measurements, use and toothpaste or rice dose were tested, with similar results to PUB and the only difference lying in including competition or games. So it would seem that game-based learning does not vary or limit learning outcomes and assessments. It is necessary to collect data from the TD experiment to make the conditions of the precision, security or usability measurement goals comparable to PUB, run experiments in PUB without competition and draw conclusions about whether game improves results and assessments.

Conclusions

Our experiments of creative challenges applied to design artefacts showed that creativity was stimulated without affecting the learning outcome, which was successfully achieved. Neither were academic results markedly affected, with minimum variations in grades. More motivation was detected in most of those students who took a positive attitude and shared a good environment with their classmates. Some students showed disinterest, usually with difficulties in constructing artefacts, and they habitually took the first valid option and settled for a pass mark. However, these data were not quantified.

Proofs of concept were not definitive, but should be taken as evidence for performance, which will improve when a larger number of experiments and tests are performed to set learning. The development of artefacts that can be improved and updated allows escape from intuitive thinking, which is supported by paper to error-based learning to do more tests to improve records and optimise artefacts.

The assessment with NUF metrics is less important for assessing concepts than goal-based metrics, but they must be applied as game and design project conditions to exceed the state of the art. Those based on goals are more precise but involve a more accurate definition and applying some kind of mathematical function to establish the final student ranking.

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