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The Carnivorous Yoghurts: A “Serious” Escape Game for Stirring Labs

Lilian BEZARD^a, Marie DEBACQ^{a,b,*}, Astrid ROSSO^a

^a Cnam, 292 rue St Martin, 75003 PARIS, France

^b Université Paris-Saclay, INRAE, AgroParisTech, UMR SayFood, 91300, MASSY, France

* Corresponding author: marie.debacq@agroparistech.fr

Authors are listed in alphabetical order.

Highlights

A serious escape game based on cards has been created for the preparation of stirring labs.

The implementation was successful: learners became autonomous, very efficient and were excited about the pedagogical game.

The game material is fully available in French and in English for use in other contexts.

Abstract

This paper presents feedback on the implementation of an educational escape game to replace the first hour of a 4-hour lab session.

Two problems were encountered when teaching stirring in chemical engineering labs: on the one hand, learners had difficulties preparing calculations before practical work, as they were unable to find out by themselves how to calculate dimensionless numbers from measured quantities; on the other hand, manipulations during stirring labs are extremely easy or even boring: learners just have to implement the tank, vary the rotation speed, read the torque value, change the stirrer and start over.

The goal of the educational escape game we have developed was to make the working data of the lab meaningful by preparing the lab session with the learners for one hour. We also wanted to make them autonomous during the lab session and make the stirring lab session less boring. With the introduction of this one-hour game, the lab session was reduced to three hours; this was not a problem however because -thanks to the game- the learners were much more efficient and got straight to the point during the practical work. The game “Carnivorous Yoghurts” is a card game, along the lines of popular domestic escape games, developed by one teacher and two pedagogical engineers.

The implementation of this educational game was successful: the learners became totally autonomous, very efficient and they were excited about the game. The engineering skills of stirring labs are still acquired, probably in slightly greater

depth thanks to the "flow" effect; traditional soft skills achieved during labs are strengthened (teamwork and communication) and new soft skills are acquired (cooperation and decision co-construction).

Keywords

Escape room; pedagogical game; chemical engineering; labs; autonomy.

1. Introduction

“le Cnam” is a French institution dedicated to professional lifelong higher education. The learners are adults and workers (therefore with scheduling and availability constraints); their initial training, level and ability are diverse.

Starting in Japan, the United States and different places in Europe, escape rooms have flourished in the last decade, for fun adventure experiences with family or friends or for professional team-building activities. Players work together in a team to find clues around the room and solve enigmas, in order to escape from a locked room, in a given time (usually about one hour). The number of teachers implementing escape games in the classroom is gradually increasing. Two main reasons explain this trend: on the one hand, the institutions and the research community encourage pedagogical innovation to make learners more active; on the other, two main characteristics of escape games (enigmas and just 1h of play), make this kind of activity particularly well adapted to an educational context. So, there is nothing surprising in the rise of “serious escape games”.

In the chemical engineering curriculum (Bachelor of Science level), stirring labs are important (they are one of the major unit operations in chemical, pharmaceutical, food... engineering), but boring (very simple activities and repetitive manipulations). In addition, learners find it difficult to obtain the right expressions to calculate the dimensionless numbers required to characterize this operation from the quantities measured on the pilot tank. Based on some studies about serious games in general (Alvarez et al., 2016; Bodnar et al., 2016) and serious escape games in particular (Borrego et al., 2017; Guigon et al., 2018; Vörös and Sárközi, 2017) and considering the benefits of such approaches, we thought that a serious escape game could be a good answer to these two issues with stirring labs.

These pedagogical games are currently developing for two main reasons (Duquesnoy et al., 2019): first, they present complex tasks allowing learners and their teachers to take stock of the integration of a particular aspect (or a whole set) of knowledge and know-how; second, they have a recreational dimension and, above all, they involve teamwork, which is a transversal competence to be acquired, whatever the level of education (Azizan et al., 2018).

When listing the main characteristics of a game (Bezard et al., 2019b; Lacombe and Féraud, 2019), one realizes the very strong similarity to teaching. Bruckman (1999) also invite to “make the learning inherently fun” and consider that “learning by making things is one useful approach that is both fun and educational”; she suggests moreover to “provide social support for learning”, “whenever possible”.

For McGonigal (2011), games are omnipresent and engaging in a game is above all a turn of mind: by adopting this turn of mind we get good results in many areas, including learning. Chou (2015) analyzed the different types of players, how a game adapts to the type of player and how during the game, the game itself evolves to maintain the pleasure of playing. One very important feature in a game is progression (Muletier and Bertholet, 2014): we start by learning to play (rules and interactions, with others and/or with a medium); we then learn to master the game (first to win and therefore acquire skills; then we play it again to get a better result or to be more efficient, e.g. to win in less time or get more points); the next step is to learn how to "flout" the game (cheat, change the rules); finally we learn beyond the game (to communicate, to cooperate, to anticipate, to speak English, ...). In this description there are again many parallels with teaching.

Dehaene (2018) argued that the four pillars of learning are:

1. attention (focus to amplify): focusing your attention on an object of thought blinds you to other stimuli. We have all had the experience of being so absorbed in an activity (depending on the person, it may be playing, reading, sewing or debugging a computer code) that we didn't realize that it's long past lunchtime and that the feeling of hunger did not even distract us from what we were doing; this state of extreme concentration is as useful in the context of learning as in that of carrying out a task;
2. active engagement (engaging to produce): a passive organism does not learn; the person must be curious, go deeper and make an effort. Here we find the well-known notion of active learning: we retain much better what we have sought and constructed than what we have simply read or listened to passively; we remember the trapezium rule to calculate an area under a curve, not because we learned the formula of the area of a trapezoid by heart but because we applied this calculation method to obtain the yield of reactors;
3. feedback on errors (compare to correct): making mistakes is essential for progress; it must be de-dramatized. A student who made a big mistake in an intermediate assignment or exercise, if we explain to him exactly why what he did was wrong, will never make that mistake again: neither in the final exam nor in his professional life. It is

also important to make clear that the errors made during learning are not that serious and that what needs to be remembered is not the error itself but the correct reasoning or the right approach acquired thanks to the error;

4. consolidation (automate to fluidize): the automation of mastered tasks frees up intellectual resources for other challenges. Once a methodology is well understood, it needs to be repeated until it becomes automatic, so that it can be applied without conscious thought and thus release the person's cognitive capacities for the resolution of new problems. When a chemical engineering student masters how to write the energy balance of a reactor, he can focus his attention on the subtleties of the precise calculation of the reaction enthalpy for example.

This is in line with the concept of “flow” used in game design. In psychology, the “flow” state is the mental state in which a person performing an activity is fully immersed in a feeling of energized focus, full involvement, and enjoyment in the process of the activity, whatever the result.

In the “flow” state (Chen, 2007), the player, or the subject, loses all notion of time and of the environment around him; his capacities are totally focused on his activity which gives him a formidable efficiency. In the “flow” zone, the player must meet challenges in accordance with his abilities (Koster, 2013): if the challenge is too easy with respect to his abilities, he will rapidly be bored; if the challenge is too high in relation to his abilities, he will be discouraged; in both cases, he will quickly get lost and lose the remarkable efficiency benefits provided by the “flow” state.

Learning and playing are two complementary facets that meet the same objective: learning is part of a formal framework with a specific objective that one seeks to achieve; playing might be seen as a more informal learning activity, by developing things by accident, doing, exploring, making mistakes and going back on those mistakes. The main difficulty with educational games is to place the game in a more formal setting and to find the delicate balance between learning and fun (Alvarez et al., 2016).

A pedagogical game must have an educational specification: who is it developed for? to learn what? for which learning outcomes? The purpose of fun proposals is to integrate educational goals into a game. The construction of the educational game is then done in several phases: proposals; negotiations; prototyping or hijacking an existing game; tests; adjustments.

The chronological stages of an educational game can be summed up as follows (Lhuillier, 2011; Schell, 2014):

- a briefing to introduce a scenario (or at least a context): the immersion and the emotional register are mobilized at this stage; a quirky or wacky story is a good way to bring the players into the “flow” and at the same time to clearly play down the mistakes;

- a presentation of the objectives: a problem to be solved, a challenge to be achieved;
- to reach these objectives, the players have various resources and objects at their disposal , and can also call on their prior knowledge and background (some of them are used to play, some others not);
- feedback (gratification; pass or fail; possibly aid) is essential so that players do not get stuck and are stimulated to move forward;
- and a final debriefing, to link up the game and the targeted skills or objectives.

There are two main types of games: cooperative (which is better for most people) or competitive (some people get better results, but by “crushing” other types of personalities). The choice therefore depends on the context. In training, cooperative games are often the most suitable.

After an initial analysis of our context, considering the organization of the syllabus, learners’ profiles, buildings and lab installations, time and budget constraints, we decided to develop a collaborative escape card game. The aim was to take advantage of the state of “flow” induced by the game to focus all the learners' attention on their learning.

2. Design

At the first meeting of the project, the team decided to use the method of “rapid prototyping for learning design” for the whole stirring lab session. There were three main reasons for this choice: 1) the course already existed; 2) the time and budgetary constraints of the project were considerable; 3) the authors were familiar with the course, the institutional context and the learners’ profiles. The course, entitled “Chemical Engineering Labs: Unit operations”, is part of the first year in the Chemical Engineering degree. At the end of the course the learners must be able to apply the theoretical approaches studied in another course entitled “Chemical Engineering: Unit operations” devoted to pilot plants. The course takes place in the second semester. This course involves 7 mandatory face-to-face lab days; 6 of them are labs. The lab sessions are usually conducted in small teams of two or three learners. Due to the learners’ profiles (adults, mostly employed, with strong time constraints), all the lab sessions are usually done in a single week (therefore including Saturday). Most of the lab session subjects take 4 hours to be completed; two of them last 8 hours. As almost always for practical work on unit operations, only one pilot plant per subject is available, so there is a standard team rotation system. Consequently, the lab sessions are independent of one another and they can be done in any order. The stirring lab session is one of these mandatory lab sessions. The project presented here focuses on the stirring lab session. The engineering objective of this session is to assimilate the notion of standard tank, visualize and quantify the effect of the different types

of impellers and of baffles, be able to calculate the characteristic agitation quantities from simple measurements (rotation speed and engine torque) and try to trace the standard power curves, with or without baffles.

Originally, the 4h-labs comprised four experimental stages:

1. assemble the device: this is fairly straightforward, but it is necessary to do things in the right order, while strictly respecting the dimensional rules (standard tank) and with some safety precautions;
2. plotting the power curves point by point for different impellers (marine propeller, Rushton turbine, pitched blade turbine, anchor) in various configurations (with or without 1 or 4 baffles): learners must find out how to calculate the Reynolds number and the power number from the elements provided by the stirring motor plus a measurement of the size of the impeller; it is these calculations (in particular the power number) that the learners found difficult to establish;
3. study of the vortex at the same time as the trials of stage 2 without baffles and comparison with the predictions of correlations from the literature;
4. total homogeneous suspension of solid particles, based on the observations during stages 2 and 3.

During the first three years after the introduction of this stirring lab session in the curriculum, the teacher noticed that the students did not prepare the lab session properly and that they had difficulties during assembly (stage 1 mentioned above). She also observed that they took note of the measurements provided by the instruments (during the long and boring process) but did not know how to use them in the subsequent calculations. In addition, since this was one of the last steps and the assembly had taken too long, the teacher often had to be too directive. Over the following years, young novice teachers were in charge of the stirring labs and the organization of the session remained unchanged. When she was again put in charge of this lab, the teacher decided that it had to be redesigned.

The goal of the project was to make the lab more meaningful, make the learners autonomous in the lab session and calculations, and make the stirring lab session less boring. So, we decided to modify the session by introducing the preparation of the lab session with the learners. However, the teacher also had to supervise the other groups working on other pilot plants at the same time. The total time of the session (preparation + lab session) has to be basically the same (four hours). Consequently, we had to find a strategy to prepare the lab session with the learners (in teams) so that it would be meaningful but not boring, not very long and without the teacher constantly by their side, not expensive and quickly accomplished. So, we decided to design a serious escape game based on cards. This strategy is in line with the four pillars of learning in that the game to prepare for the lab session represents the first pillar (capturing attention), the

second pillar (active engagement) is the lab session itself, the third one (feedback on errors) the debriefing by the teacher during the last ten minutes of the lab session, and the fourth one (consolidation) takes place when writing up the lab report.

2.1. Building the game

To build the game (Bezard et al., 2019a), we first read the literature about pedagogical games, which highlights their benefits. We rapidly decided to build an escape game because we wanted a cooperative game, a level of complexity that would mobilize various skills and the possibility to prohibit learners from entering the laboratory before having solved all the puzzles of the game.

Then we played card-based domestic escape games (Exit and Unlock) and explored a French website dedicated to pedagogical escape games (S'CAPE): this step was very useful to understand the game mechanics and identify different types of puzzle. Concurrently, the aim of the game was defined, related to the features described in the introduction. After that we scripted the game (first simply on paper, see Fig. 1), clarifying the order of the main enigmas, and the simultaneity of events and places. Each enigma was divided into several steps, each one of them becoming a new enigma or a piece of the puzzle. After this first script, we began producing the cards and other material (with standard office software) and beta-testing it. Then, we decided where to include more steps or clues to guide the learners, to change the nature of some of the enigmas and to make some help cards. We repeated this process twice. And finally, we tested the game with a “crash-test” group of learners, modified it for the second group, and adjusted it again for the third group. The game was in “perfect” running order for the fourth and last group of learners.

“The carnivorous yoghurts” game is composed of several things:

- 1 sheet with the rules of the game;
- 7 “place” cards, which are actually photos of a room with visible and hidden card numbers leading to various other cards;
- 80 “object” or “puzzle” cards or sometimes “penalty” cards (see examples of cards on Fig. 2 and 3);
- 7 help cards for hidden numbers;
- other stuff: a Lab Notebook, a “ConcentrX” (circular device where it is necessary to adjust superimposed discs by turning them, to reveal a sentence or a drawing), punch cards that are placed over another card to solve one of the puzzles, and red-blue-green-yellow plastic folders.

The cost of this serious escape game was nearly zero euros: only usual office supplies and a very widely used software were needed to produce the cards and the board game. However, the design of the game took some time to mature and its production was very time-consuming. We estimate that the maturation phase took between two and three months (but not full time) and the production phase one month (with other activities in parallel, but intensive work on this project).

2.2. The scenario

The preparation phase of the labs, formerly in the form of a PDF document that students were required to read and a data sheet to study, was replaced by a fifteen-minute video presenting the fundamental principles of agitation (with no particular connection to the labs): https://youtu.be/y_IK-AVOa4s. The theoretical part of the PDF support remained available for the learners. The experimental part of the session was reduced from 4 to 3 hours. The game takes place at the beginning of the session and it has three successive levels. To limit the game to about one hour, the vortex phenomenon is not mentioned at all (but it is explained and illustrated in the video). The game master stays with the players throughout the game. The three levels of play include:

1. setting up the tank (10 points): this level of the game is based on finding and associating objects; it makes it possible to dissect all the stages of assembly, to review the ratio of the standard tank dimensions and to emphasize the safety precautions; it is deliberately simple, to help learners enter the “flow” and gain confidence;
2. establishing the expression of the Reynolds number for stirring (20 points): this level is based essentially on logic and observation; this puzzle is quite complex and may require some assistance from the game master with certain groups, in order not to exceed one hour of play;
3. establishing the expression of the power number, including the factor taking into account the units of quantities that will be measured during the practical session (30 points): this level is also based on logic and observation, but in addition, includes calculation; it is also complex, but the learners who have accomplished level 2 pass level 3 a little more easily.

The game begins with this message:

Hi,

My name's Ford PERFECT, I was the foreman in charge of our yoghurt production. Rats left their droppings in the lactic acid culture tank. At first, we pretended nothing had happened and we carried on producing as

before. But very soon the attacks started in supermarkets. A few days after having been produced, the yoghurts in our "Yogiyog" range became carnivorous. They started devouring the shoppers.

We recalled all the yoghurts in this range, it came to 250,000 units altogether. But the factory manager threatened me: he said he'd blame me for everything if I didn't quickly find a solution. He wants the yoghurts back to normal again, to avoid having to throw them all away. So time is short... especially as there's a press conference later today. There'll be Sue CROOKS, you know who I mean? the journalist... Anyway, the manager wants a solution, and fast.

I've been working on it for the last 30 hours, non-stop, but I've had enough, I really need a break. I'm going to lie down for an hour or so: I'll leave you to carry on looking for a solution... For future engineers in process engineering like you, that shouldn't be too difficult. You'll find my lab notebook on the desk.

And now, it's up to you. Start the timer and turn over the card marked zero. Get moving, there are killer yoghurts in the lab fridge! Good luck!

At the end of the game, when the learners have passed the three levels, the game master gives them a bottle containing the "miracle substance" which eliminates the effects of rat droppings and which will have to be suspended in the tank to purify the yogurts. Ultimately this bottle will be placed in a cryptograph; the first attempt to 3D-print it was fairly conclusive, but there are some details that need to be improved and we did not have enough time to complete this during the first trial of the game. A quick debriefing is done with the teacher, and the learners are then allowed to enter the laboratory to carry out the experiments.

Fifteen minutes before the end of the practical session, the factory manager (actually the teacher) inspects the total homogeneous suspension of the particles, then leaves (normally, he should be satisfied with what he sees) to go to his press conference.

The learners must then empty, dismantle and clean all the experimental device. They also complete a MCQ, as for all the other labs, but the last questions of this MCQ concern their perception about the game.

2.3. Playing the game

The game was first experimented in April-May of 2019 at Cnam in Paris (Fig. 4):

1. First the rules of the game were explained to participants and they were reminded that it doesn't matter if they make mistakes!

2. Then the game was run in pairs or groups of three learners for usually an hour, in the presence of the game master (this role was taken by the teacher) and as often as possible one of the pedagogical engineers.
3. At the end of the game, the debriefing and remediation were conducted by the teacher with the learners.
4. After a short break (needed because players were often exhausted after an hour of intense concentration; and also a good moment for the pedagogical engineer to try to get more or different feedback), the players/learners were allowed to enter the laboratory to perform the experiments; in this sense the game can be considered as a flipped escape game: solving puzzles allows you to enter the laboratory, rather than leaving the game room. With the skills acquired during the game, they proved to be sufficiently efficient to carry out all the manipulations (formerly carried out in four hours), in just three hours.

To succeed in the development of an educational escape game, the É S'CAPE website (<http://scape.enepe.fr/>), a resource pooling space, offers guidance and many tools, as well as examples of implementation. For the development of "The Carnivorous Yoghurts", we used this website many times and an article on the game is now published on it (Nadam, 2019).

4. Results and discussion

The question of the efficiency of the game is obviously crucial. It should be remembered that the objective of the game was not that the learners get better marks: the aim was to make them more autonomous and more involved.

Initially, the teacher was apprehensive that Cnam learners would not be very receptive to an educational game, or that some would refuse this non-serious activity. It was just the opposite in fact; all the learners were delighted to play the game and very satisfied after this new organizational structure of labs.

The fact that the learners were exhausted but smiling after the game is an indicator that they had indeed entered the "flow".

The game was conducted in 3 steps: the briefing (we explain the game, the rules of the game, the role of each person, the place); the game itself; the debriefing (we come back to the learning objectives of the activity and the skills).

In a serious escape game, the successive puzzles must enable both entry into the game and achievement of the educational objectives. We therefore divided the game into 3 levels:

1. entering the game, which corresponds to the start of the activity: it involves giving learners easy puzzles to solve, in order to encourage them to continue their efforts; in this stage we therefore favored observation and manipulation; this phase serves as a boost;
2. recreational consolidation: during this part, the puzzles are more diverse and increase in difficulty; the enigmas of the game intersect the educational objectives (how to set up the experimental device, what are the measurement units, how to implement the device safely);
3. pedagogical consolidation: at this point the game stages the most complex elements of learning through complex puzzles (in this case, the equations). This is the most sensitive stage to manage in order to keep the learner / player in the "flow": he must not drop out because the task is too difficult and must maintain intense concentration to successfully solve a complex problem.

The evaluation of the pedagogical game was carried out in several stages: informally, on the spot just after the game (before entering the laboratory) with one of the pedagogical engineers who co-designed the game and without the presence of the teacher; in the end-of-session paper MCQ; in the end-of-course survey two months later; and finally by an open questionnaire seven months later.

Considering the small number of learners involved in this first experiment (nine), it does not make sense to present statistics, but we can note the following points:

The on-the-spot discussions confirmed that the learners reacted positively. Some even suggested ideas for improvement. Several encouraged us to push the wacky story further.

In the end-of-course survey, to which five learners replied, all described the game as "attractive"; the other most frequently used qualifiers were "pleasant" and "useful for learning". Learners found that the value of the game lay more in carrying out the lab session than in preparing it. On the balance between fun and learning, 4 out of 5 found the game "well balanced" and 1 "too playful". The terms most often used to qualify the scenario of the game were "relevant" and "enlightening". None of the negative qualifiers proposed to evaluate the game were checked. Concerning the duration and the level of difficulty of the game, learners considered that the duration was "appropriate" to "a bit too long" and that the level of difficulty was "appropriate" to "a bit too difficult". The presence of the game master (here the teacher) was judged, by order of occurrence among the responses: "necessary"; "caregiver"; "reassuring". In the free comments,

many positive and encouraging comments were made. The interest of cooperation in the group and the complementarity of skills were mentioned several times.

The question of activity perception is important in assessing the impact of the involvement of learners. Here the game brings together the two impacts commonly sought in this type of activity: pleasure and skill. Pleasure is important because it promotes memorization. Unfortunately, only two learners answered the questionnaire seven months later, but both correctly answered the question aimed at checking whether the skill required to understand dimensionless numbers had been durably acquired. One learner who was particularly mature and sensitive to pedagogical questions, explained that he appreciated the construction of knowledge during the game by association of ideas and collaborative construction step by step.

As mentioned above, given the small number of learners concerned, it would not make sense to present quantitative results, for example by comparing the scores obtained by the 4 groups in the stirring labs the year the game was deployed with the average of the grades from previous years. It turns out that their marks were better, but we were also dealing with very good students overall that year, and it would not be honest to claim that their better marks are the effect of the game. This is why we prefer here to stick to the comments and reactions reported above.

This is in line with Kirkpatrick's Four Levels of Training Evaluation (2016), first published in 1959 by Professor Donald Kirkpatrick and recently updated by his son and his wife. In this model, level 1 of evaluation is "Reaction" i.e. measuring how engaged the learners were, how actively they contributed, and how they reacted to the training, helps to understand how well they received it. We tried to apprehend this level 1 of the evaluation thanks to the "on the spot" discussions and the end-of-session paper MCQ. Kirkpatrick's level 2 "Learning" measures what learners think they'll be able to do differently after training, how confident they are that they can do it, and how motivated they are to make changes. We asked questions along these lines in the end-of-course survey. Kirkpatrick's level 3 "Behavior" helps to understand how well people apply their training. This was the purpose of our open questionnaire seven months later; unfortunately, only two responded and even if their answers are satisfactory, it is not enough to affirm the long-term effect of the game. Kirkpatrick's level 4 "Results" is the only one where one tries to quantify the effects of training. This level cannot objectively be claimed in our case. Reusing the game for another 1 or 2 years and/or transferring it to another institution could give more quantitative results in the future.

We can claim that the goal has been achieved: this lab session is less boring; the learners are totally autonomous and very efficient. This is because at the end of the game, they know exactly how to implement the tank and have the equations to calculate the dimensionless numbers from the measurements (with the right units and coefficients). The game has the desired effect of any pedagogical game, namely immersing the learner so that he focuses all his cognitive abilities on the purpose of the game. The practical work is still performed, but is reduced from 4 to 3 hours. Since the learners have gained autonomy and efficiency thanks to the game, this time is more than enough to carry out the same experiments as in the past. Thus engineering skills specific to the topic of stirring are acquired (standard tank, effect of types of impellers and baffles, power curves), but also transversal scientific skills (in particular the use of units to guide reasoning on physical quantities) and soft skills (working and communicating as a team, making joint or shared decisions).

Learners unanimously state that the game master should be present throughout the game: his/her attendance seems necessary to help learners during the game; but this probably inhibits players-learners who do not dare to try (and sometimes fail). And above all, other groups are working in parallel on other pilot-plants and the teacher also needs to teach and help them out at times. It would be great to have a different person to master the game.

The scenario could have been a simple simulation, or something very serious. A wacky topic was used to design a scenario and therefore an activity with no other stake than the game itself: learners do not receive a mark for the game; they can fail with no consequences in real life; they are under no outside pressure to succeed in the game. They are in a blurry area which is a teaching moment, but which is not entirely so. The wackier the scenario, the further the metaphor is from the subject, that is to say the further the story of the game is from the concrete context of the skills, and the longer the debriefing will be to bring the experience of the game back to reality and pedagogical objectives.

The feedback on the wacky scenario at the end of the lab session (when the factory manager inspects the tank before going to his press conference) was welcomed by the editor of the article presenting our game on the É S'CAPE website, who is also the co-author of a very recent work on pedagogical escape games (Fenaert et al., 2019).

4. Conclusions and perspectives

As a conclusion, one should always remember that a pedagogical game is a tricky balance between an educational scenario and having fun. Some keywords should be highlighted here: immersion and emotions are very important in such an

experience; true gamification is required for a pedagogical game, which should not be a mere simulator; finally, feedback is crucial.

The objective of an educational game is often to intervene on part of the syllabus that is problematic, either because it is too complex, too conceptual, or too boring. The game brings a dimension that solves a difficulty. Through pleasure and commitment, learners overcome this difficulty.

To summarize some guidelines for developing a pedagogical game: clear goals must be well defined upstream, explained at the beginning of the game and validated at the end; the screenplay is essential, so as not to forget the learning objectives: the first stages of the game must be easy (so that learners get immersed in the game) and the scenario must allow them to remain in the “flow”; all the material (the cards and other stuff) should be designed to help players stay in the “flow”; debriefing should not be neglected and must reconnect the game to goals and skills (and the rest of the teaching); the atmosphere of the game should lead learners to try things out: the principle of trial/error is very important in the process of learning with a game; always iterate to adjust the level of difficulty: if no one is available to test upstream, it will be necessary to inform the first groups that they might be in “crash-test” mode; teachers tend to include too many concepts in a game, which is harmful; the sustainability of the game should be considered, because some game mechanics can quickly become obsolete; and last but not least, have versatility in mind from the beginning, that is: try to design a game concept that can be applied to other cases, in the hope of saving time in the development of future games.

In our experience, educational games present six main advantages: capturing the attention of the learner; playing down mistakes; promoting peer exchange; increasing learner involvement through playing; leaving a lasting effect on the learner's memory; allowing the learner to self-assess and have feedback with the teacher.

One can find a very useful guide for the design, the animation and the evaluation of a fun-educational activity, based on Alvarez's work, at the following address: <https://urlz.fr/aBn1>

The main risks when developing an educational game are:

- producing an ineffective game (too complex, with too many things in the game, too far from the educational objectives, too boring, too old-fashioned);
- not having been able to create the appropriate “atmosphere” for the game to develop, i.e. to be in a situation where the game cannot take place properly: the learners do anti-game (because they do not join this educational form) or even firmly refuse to play. In any case it must be said to the learners that they are going to play; when

we assume that this kind of behavior can happen with learners (who refuse to become players), we must forecast a fallback plan.

While building the game, it is necessary to keep in mind: the importance of the atmosphere (so that learners do not hesitate to try, and make mistakes); iterations to adjust the difficulty of the game (one or more crash-test group(s) are essential to test the game); durability (some game mechanics can quickly become dated); if possible, a game concept that can be reused on other cases to make the long development time cost-effective.

The game “Carnivorous Yoghurts” is now adopted for stirring labs and will be replayed every year. Several colleagues from other universities have expressed interest in transposing the game with their students.

The game material is therefore fully available for anybody in French and in English: <https://hal.archives-ouvertes.fr/hal-02396374>

The instructions for use of the game material ask the teachers who use it to give feedback about this educational innovation for stirring labs. We are looking forward to reading this feedback.

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Figures

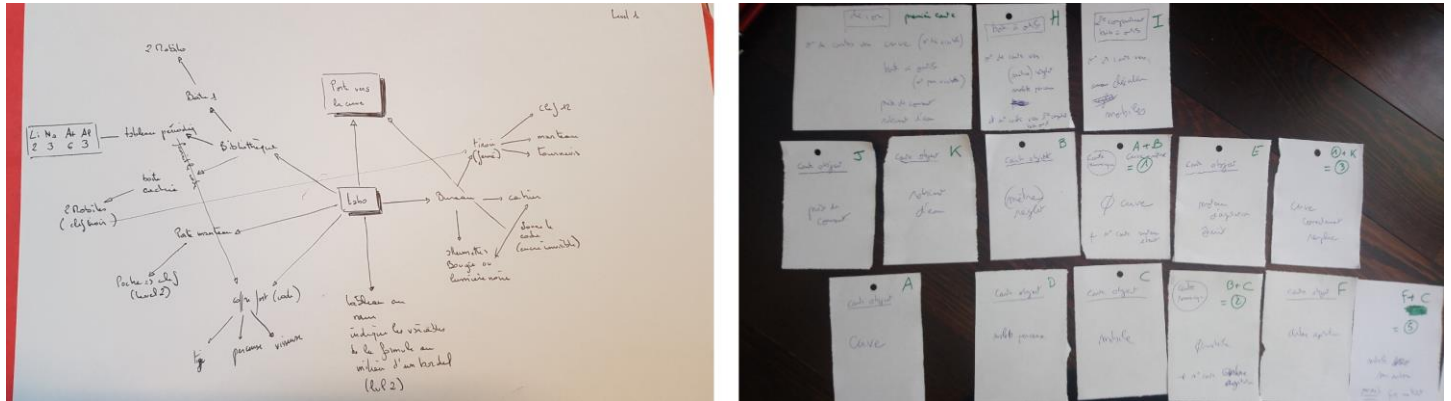


Fig. 1. Scenario construction on paper.

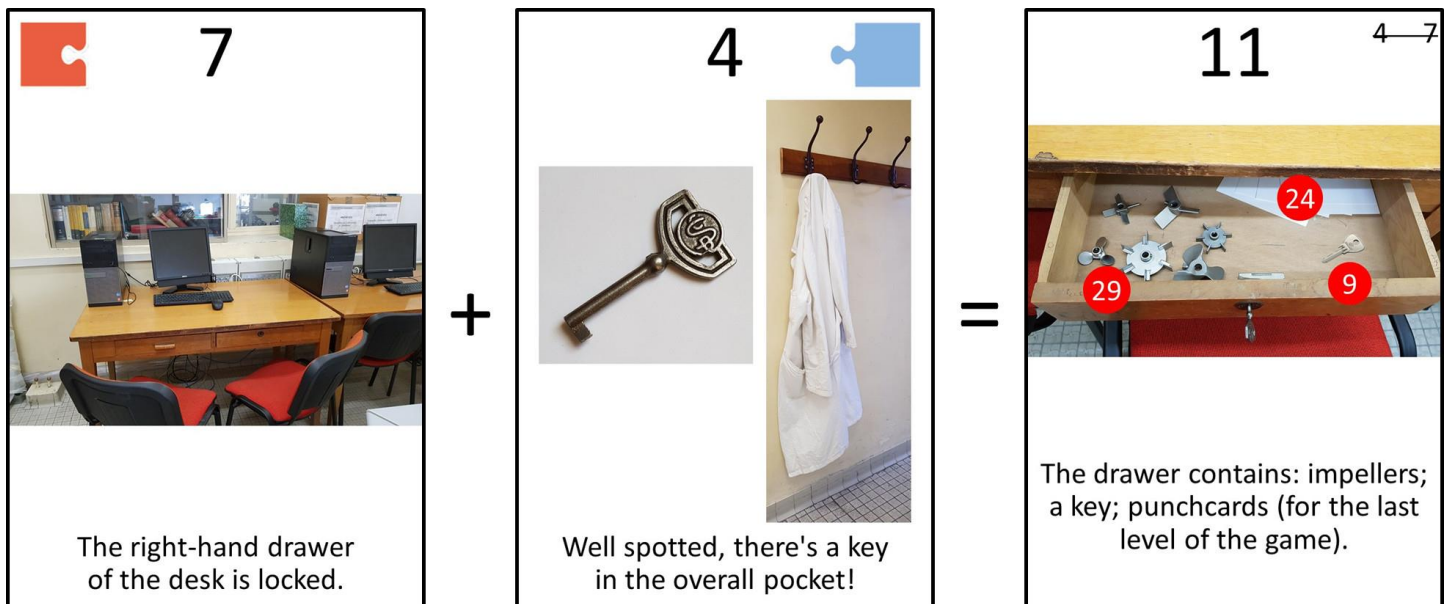
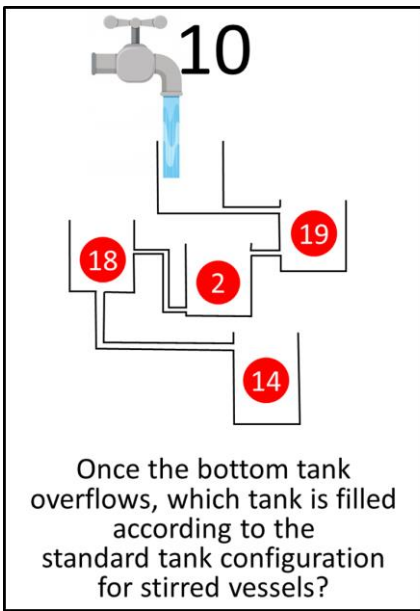


Fig. 2. Example of how cards are combined in order to find new objects and puzzles.



27

$+$
 $+$
 $= 150$

$+$
 $= 56$

$+$
 $= 15$

$+$
 \times
 $= ??$

a puzzle for Facebook wizards
(and chemical engineering geniuses)



Fig. 4. Learners during a session.