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The CHEM Jam - how to integrate a game creation event in curriculum-based engineering education

Sílvia Fornós[a,*], Chioma Udeozor[b], Jarka Glassey[b], Daniel Cermak-Sassenrath[a]

[a] IT University of Copenhagen, Rued Langgaards Vej, 7, 2300 Copenhagen, Denmark
[b] Merz Court School of Engineering, Newcastle University, NE17RU Newcastle upon Tyne, United Kingdom

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ABSTRACT

To tackle future sustainability and energy issues, novel learning approaches should be considered in chemical engineering education, particularly those encouraging learners' problem-solving skills. This paper proposes an example for educators to integrate game-making activities into a chemical engineering curriculum. The specific activity proposed is a collaborative event, known as a game jam in Game Studies. Participants use a custom-made Game Editor for Learning to design levels for a jump n′ run/platform game. The editor facilitates the construction of games for non-game designers, has a tutorial, and is provided with inspirational gameplay videos of level examples and a template for facilitators to assess the resulting levels. This paper argues that prompting learners to create levels based on chemical concepts and structures, challenges and develops their problem-solving skills, and makes the activity valuable to be integrated in present engineering educational programs. The learning experience, named CHEM Jam, starts with an introductory phase during which participants receive essential guidance, while preserving the effectiveness, of learner-centred activities. The assessment methodology is aligned with the learning objectives of an undergraduate process design course. Finally, research and critique on the activity and how chemical engineering can benefit from game-making events and communities is discussed.

1. Introduction

Learner-centred teaching which emphasizes learners' exploration and experimentation (Aubrey and Riley, 2016, p. 2–4), is continuously attracting academic attention (Kafai and Vasudevan, 2015; Paciarotti et al., 2021; Roque et al., 2016). Among its advocates, Mitchel Resnick argues that a kindergarten-style learning should be offered to learners of all ages (Resnick, 2017, p. 7). In early education, infants are given tools, e.g. toys or puzzles, to imagine situations, explore and create. This type of learning, he argues, is exactly what is needed to develop capacities necessary to thrive in our rapidly changing society. Educators cannot give the specific solutions of future problems but can facilitate an environment for learners to think critically and solve problems creatively.

In chemical engineering education, research (Varma and Grossmann, 2014; Ellis et al., 2005, p. 1148–1150) posits that, to tackle future sustainability and energy issues, novel learning approaches should be considered, particularly those encouraging learners' problem-solving skills. Based on the mentioned studies, this paper proposes a CHEM Jam, a learning experience inspired by game jams, hackathon-like events to create games in a relatively short period of time (Kultima, 2015).

Through a CHEM Jam, students are confronted with the challenge to create a game level about the learning content, i.e. engineering process design. The experience intends to present a thought-provoking assignment to practice content learnt in class creatively. But, unlike conventional assignments, the CHEM Jam is an empowering experience. Learning by designing interactive artefacts represents an empowering activity that can be used to motivate learners (Gee, 2005, p. 7).

Collaborative learning is encouraged during the creation process (Fornós, 2020a). In other words, by creating game levels in teams, participants learn from each other. It is obvious that beginners can learn from more experienced students, but participants can also get empowered, corrected or inspired by explaining what they know. In fact, learning extends beyond group members since participants can observe other teams' creations and discuss relevant issues. An effect of using an artefact so representative of pop culture as a digital game is that students may want to share their creations with family and friends, which would

* Corresponding author.
E-mail addresses: info@silvia-fornos.com (S. Fornós), chioma.udeozor@newcastle.ac.uk (C. Udeozor), jarka.glassey@newcastle.ac.uk (J. Glassey), dace@itu.dk (D. Cermak-Sassenrath).

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lead to new learning opportunities. In this respect, the CHEM Jam looks for successful innovation by contextualising education within cultural trends such as games and game jams (Papert, 1980, p. 181).

For the present study, a prototype of a custom-made Game Editor for Learning (G.E.L.) has been developed, through which students can create the levels without necessarily having any programming skills. Additionally, a customised assessment model is included to assess the learning content represented in the creations. Adapting the assessment framework presented in a previous pilot study (Fornós and Cermak-Sassenrath, 2021), this paper facilitates an assessment to apply in an undergraduate process design course. If levels are created in line with the assessment criteria set out in this publication, the CHEM Jam can be effectively integrated in an undergraduate chemical engineering course.

One of the most common criticisms of learner-centred activities is that they only start to be effective when learners can employ internal guidance, that is, when learners have sufficient prior knowledge (Kirschner et al., 2006). This is mitigated by explaining the CHEM Jam's structure and assessment, which offers participants the essential minimal guidance, while preserving the effectiveness, of learner- centred activities.

This publication introduces a CHEM Jam event and proposes its integration within an undergraduate process design course. To help practitioners organise a CHEM Jam, the supporting material in this publication includes the G.E.L. free download link, a tutorial for first-time users, an assessment template and three gameplay videos of level examples.

The proposed activity is not limited to chemistry or chemical engineering and can be used as inspiration to organise engaging game-making events, using either the G.E.L. or other tools, to propose challenging activities in STEM (Science, Technology, Engineering and Mathematics) disciplines.

2. Learning approach

The CHEM Jam is an activity structured in three stages as shown in Fig. 1.

The tasks conducted throughout the stages, introduced with bullet points in Fig. 1, trigger different types of engagements in learners, representing Chi's four modes of engagement in the ICAP framework, i.e. passive, active, interactive and constructive (Chi and Wylie, 2014). What type of task and how learners are engaged with each task is discussed next.

2.1. Introductory stage

The introductory stage of the CHEM Jam presents a workshop that

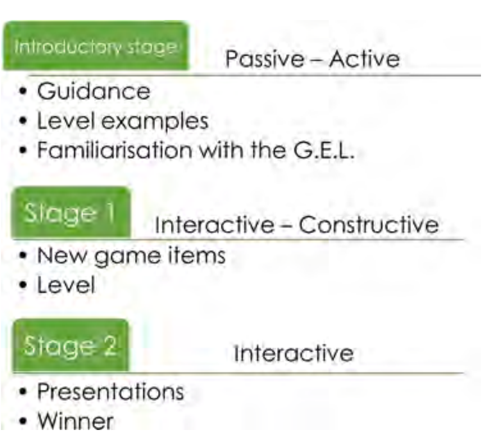

Fig. 1. The stages of the CHEM Jam in green, the type of engagement on the right and the tasks conducted in each stage in bullet points.

explains the structure and assessment methodology of the activity to the participants (Fig. 1). The assessment methodology, which is described in detail in Section 3, evaluates the game levels mainly in terms of learning content to frame the CHEM Jam in the process design course. Certain level examples, included in the supporting material section of this publication, are shown for inspiration, even though an experimental and innovative approach during the level creation cycle must be highly encouraged. Next, the familiarisation process with the G.E.L. begins, through which participants get to use and test the editor. Documentation for first-time users is facilitated.

During the first part of the workshop, participants are basically listening to information and so the type of learner engagement is passive according to the ICAP model. However, in the familiarisation process, participants need to engage actively to download and use the G.E.L. in their computers.

2.1.1. Game editor features

The G.E.L. is a custom-made editor through which users can make, test and play 2D platform game levels. The editor is an enhanced version of the open-source Felgo's Level Editor for Platformers (Felgo Level Editor, 2016). Jump n′ run or platform games are a type of action game in which typically the main character or avatar, controlled by the player, must jump and run to avoid obstacles and/or defeat enemies (Minkkinen, 2016; Fornós, 2020b, p. 804). Platform game editors allow designers to create game levels, usually by dragging and dropping pre-made game items into the level which means that programming skills are not required (Marone, 2016, p. 9).

The G.E.L. features a drag-and-drop system to create the levels. Participants can use the existing items in Table 1 for the creations. Additionally, unlike with other popular drag-and-drop game editors, G.E.L users can skin game items with an image of their choice. In view that the type of available interactions in the G.E.L. is quite limited, exploring how to integrate the learning content and conveying a message within this limitation is part of the challenge and, hence, of the learning experience.

To skin game items and create new game items, users select the 2D image that they wish to use, upload it to the editor and assign one of the item types (Table 1), which define how items interact in the game play. As a result, users can make new game items that interact like the existing terrain items, enemies or power-ups, but look like items typically used in or related with chemical engineering processes. Therefore, the chemical engineering content can be integrated in the game levels through the creation of new game items.

To give an example of how new game items can be created and used in the G.E.L., Fig. 2 shows a screenshot from a game level created with the G.E.L. that includes four new game items.

The sign "reaction vessel" and the chemical reaction formula to produce ammonia is a new game item that interacts as a neutral terrain item, that is, it is motionless. The reactor is also a neutral terrain item that the avatar (in pink) can reach and use as a platform to jump on it. The ice and fire elements are two game items with a positive and a negative behaviour, respectively, to indicate that the reaction will occur faster at higher temperature.

2.2. Stage one

In stage one, participants work collaboratively to create levels with the G.E.L. Participants, working on one computer per team, start by deciding which new game items need to be created for the level. The new game items may be related to the unit operations that have been included in the engineering process that creators have designed in the course. Teams can use their process flow diagrams, generated with a simulation program, for a global view of their process design and unit operations.

Once the new game items have been created, students can proceed with the level creation combining existing and new items. The levels

Table 1
Existing game items in the Game Editor for Learning including category, type, interaction and feedback in the gameplay ((Fornós and Cermak-Sassenrath, 2021)).

Category	Type	Interaction	Feedback	Existing images
Terrain	floor tiles	motionless	neutral	
	sharp elements	motionless	negative	
Enemies	jumper	jumps	negative	
	rodent	side to side	negative	
Power-ups	star	motionless	Positive (invincible)	
	mushroom	motionless	Positive (super jump + extra life)	
	coin	motionless	Positive (+1 coin)	

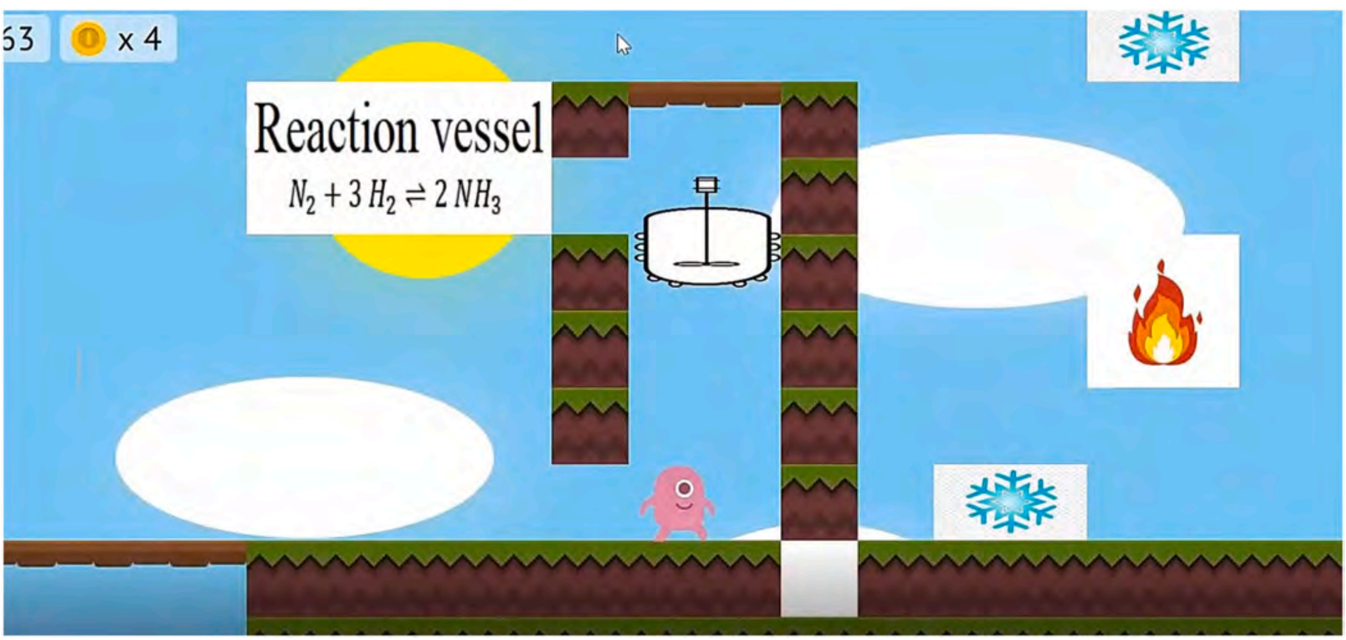

Fig. 2. Screenshot of a game level created with the G.E.L. in a pilot study including new game items, i.e. the reaction vessel and formula sign, the reactor image, fire and ice elements.

should be used as an interactive, informal channel through which students can communicate what they are learning in class. Using images and representations of details, chemical/physical phenomena or other information related to process design that are usually not represented by process flow diagrams or simulators will have a positive impact in the creativity criterion of the assessment.

During the level creation process, participants need to adopt a constructive behaviour. Unlike in the ICAP model, this paper argues that this type of engagement occurs only when, as a result of the learning experience, an artefact is generated. In the case of the CHEM Jam, a digital game level is generated as a result of the creation process. Additionally, the interactive behaviour is triggered by creating collaboratively.

2.3. Stage two

In stage two, participants present and explain their levels through a gameplay video, that is, a video showing a play-through of the level created. This study assumes that this sort of activity requires learners' active engagement. Students who are not presenting can interact by asking questions and/or comment on other students' creations.

Finally, the CHEM Jam's facilitators provide constructive feedback about the levels based on the assessment criteria. The team with the highest score is declared winner of the CHEM Jam, which introduces a competitive element that supports learning. In fact, the elements of competition and time restriction in game jams are intended to foster innovative thinking, rapid problem-solving, an iterative approach, and the development of a strong team dynamic (Kafai and Vasudevan, 2015,

p. 7). Therefore, these elements should be maintained within the limitations of the educational framework.

2.4. Recommendations

The CHEM Jam should preferably be facilitated in an informal space, e.g. a lounge area with internet connection and a big screen, where food, snacks and drinks are offered. The space is especially relevant to create an inspiring environment. The creation process (stage one) should take at least 6–8 h.

Game jams are normally held for two or three days during a weekend. However, to integrate the CHEM Jam in a process design course, it is advised to organise the event ideally on three non-consecutive days during the semester, with each day corresponding to one of the CHEM Jam's stages. The introduction session can take place in the beginning of the semester, but it is preferable to organise stage one and two towards the end. By then, teams will have a clear picture of their process designs, and thus, of the elements to represent in the game levels.

3. Assessment

Generally, measuring learners' understanding in student-centred activities entails some difficulties. Popular measurement methods, such as a pre-test/post-test design (Dimitrov and Rumrill, 2003) or constructive alignment (Biggs and Tang, 2015), are not effective to assess learning during the CHEM Jam, mainly due to the creative nature of the experience.

To tackle this difficulty, this study proposes to measure understanding through the lens of the artefacts created during the experience, that is, the game levels. Learner-centred activities can be effectively integrated in curriculum-based education if the assessment of the specific activity is aligned with the learning objectives of a course in the curriculum. Hence, the assessment framework presented for the CHEM Jam has been aligned with the learning objectives (Fig. 3) of the undergradguate Process Design course at DTU (Danmarks Tekniske Universitet).

The first task of the course is designing a concept in which engineering, chemical, physical and mathematical principles are applied. Process design problems in the concept are identified and solutions are given with the help of a process simulator (PRO/II). Next, a process flow diagram is created. Students continue with the design of the specific unit operations considering economic, environmental, safety and ethical aspects. Finally, during an oral exam, students present a final report that recapitulates their work along the course.

Even if different tasks are allocated for each learning objective, all the in- tended learning outcomes (ILOs) are interconnected, which is represented with arrows in the diagram. To create an efficient process design, students must attain each ILO, which corresponds to the tasks in the circles (Fig. 3). The green-marked ILOs are the ones directly represented in the game levels and on which the assessment framework (Fig. 4) is based.

Through the assessment framework, inspired by Brüssow and Wilkinson's work on assessing concept mapping activities (Brüssow and Wilkinson, 2007), the learning content in the game levels can be assigned a score. The team with the highest score is declared the winner of the CHEM Jam. Beyond the competitive aspects of the activity, the event constitutes a valuable experience through which students receive constructive feedback about their projects.

The organisation criterion in the assessment framework aims to evaluate if levels respect the logic flows and relationships of phenomena/equipment and unit operations. If needed, assessors can compare game levels with the process flow diagrams. These diagrams can also provide more information about the criterion *unit operations*, which assesses if the core unit operations of the process are represented in the level.

Levels showing economic, environmental, safety and/or ethical factors will be graded positively in the *optimisation* criterion. Alternatively, if one or more factors are not represented in the level, participants can give an explanation during their presentations. Finally, the criterion *creativity* measures how creative the representations in the levels are to encourage innovative game levels beyond the inspirational examples.

Regarding the scoring system to grade each one of the criteria, we suggest using a scale ranging from 3 to 0. Three points should be given to a criterion that is "Achieved", which means that the level shows no mistakes or improvements in that category. Two points means that the information represented for that category is "Correct but limited", i.e. good process design practices that can be improved. In this case, suggestions for improvement should be included. One point equals to a criterion that "Needs revision", that is, an incorrect process design practice that should be corrected. Major mistakes should be highlighted in one-point grades. The zero-point score is reserved to categories that are "Not included" and, therefore, cannot be assessed. The missing content should be pointed out. This assessment model will provide the participants with information about challenges encountered to integrate particular categories during the level presentations (stage two). For instance, participants may find difficulties to represent ethical aspects, in which case they should mention it during the presentation and explain which ethical factors have been considered. The scores should therefore contemplate the game levels together with the information facilitated during the presentation.

3.1. Case study

In the supporting material section, three game level examples representing cumene production are included. These examples were created during an intervention conducted in Autumn 2021, in a collaborative event between IT University of Copenhagen and DTU. During the introductory stage on 21/09/2021, the CHEM Jam was explained and

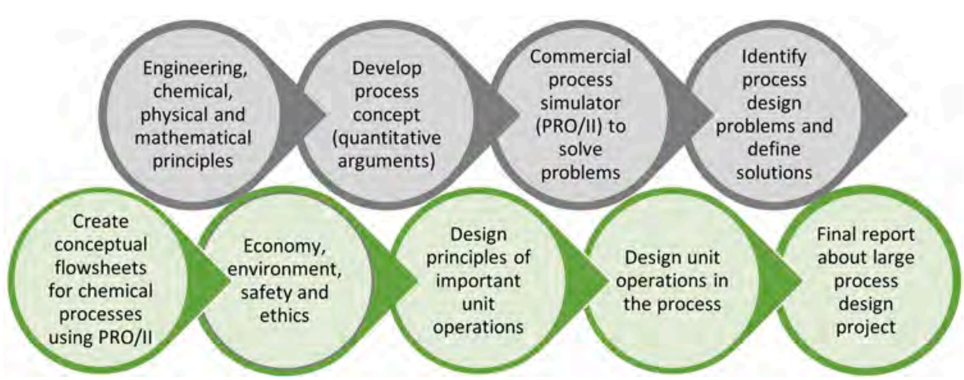

Fig. 3. Intended learning outcomes of the Process Design course at DTU. The green-marked outcomes are directly connected with the CHEM Jam whereas the grey ones are connected indirectly.

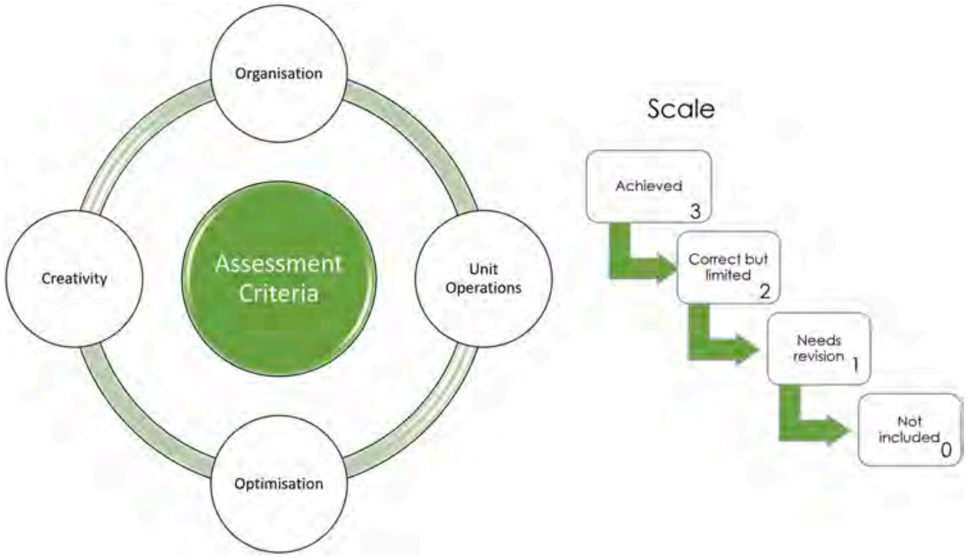

Fig. 4. The CHEM Jam's assessment framework including assessment criteria (left) and grading scale (right).

presented as an optional activity.

Stage one lasted 4 h on 20/11/2021 and 22 students out of 48 students enrolled in the course participated in the event. Since the stage one was on a Saturday and the activity was announced in very short notice, the students, organised in teams of 3–5 members for this course, were informed that participation was possible even if all the members of the group could not attend. However, it was advised that teams should comprise at least 2 members to encourage collaborative learning.

Five teams intended to present their levels on 30/11/2021, but two of them arrived late and the presentation was not possible. The three presented levels were assessed according to the assessment framework and the team with the highest score was selected the winner of the CHEM Jam. Finally, participants were given the choice to present their game levels in the group-based oral exam on 14/12/2021 and 9 groups out of 12 presented a game level.

In this section, example 1, corresponding to the CHEM Jam winner, is assessed with the CHEM Jam's assessment framework to demonstrate the applicability of the framework (Fig. 5).

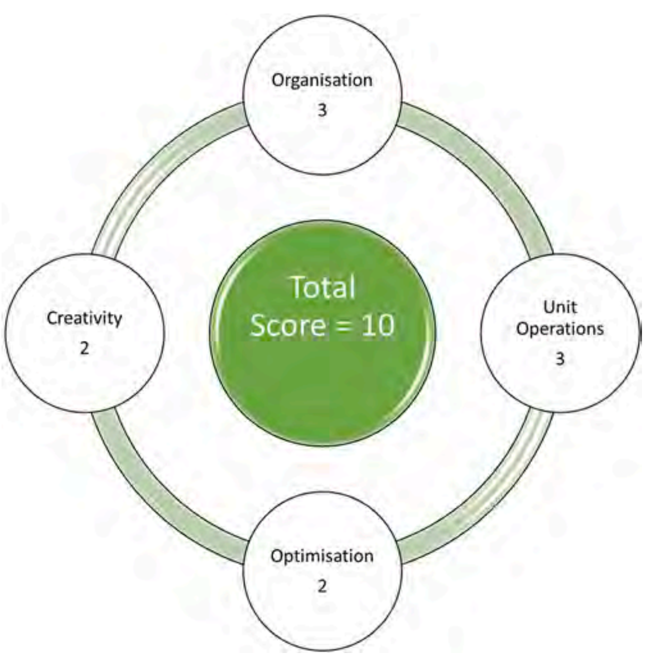

Fig. 5. The assessment of a level example.

Supplementary material related to this article can be found online at doi:10.1016/j.ece.2022.04.001.

The total score of the example 1 is 10 points, which have been awarded in line with the following argumentation.

Organisation – 3. Achieved.

The stream flow is represented in the level quite clearly, and the explanations during the presentation cleared any confusion. The video starts with the two reactants (blue and red stream flows) which are mixed and heated. They react to produce cumene (purple stream flow) and a byproduct. Next, the stream is cooled and flash-distilled to prepare the separation of the reactants (which are recycled) from the product (cumene) and byproduct. Finally, the product and byproduct are separated too.

Unit operations – 3. Achieved.

All the core unit operations in the process according to the process flow diagram (PFD) in Fig. 6 have been represented in the level.

The PFD for cumene production in Fig. 6 consists of the following unit operations: stream mixers, compressors, heat exchangers, reactors, distillation columns and condensers. (Fig. 7).

Optimisation – 2. Correct but limited.

The overhead product is recycled, which optimises the design. During the presentation of this level, ethical factors were explained too. The process could have been improved by considering other sustainable or environmental aspects.

Creativity – 2. Correct but limited.

The level shows a creative representation of engineering processes. One feature was especially creative, involving the avatar's change of appearance. The avatar changes, from big to small, to communicate a phase transition and a rise in temperature. During that, the stream evaporates and gets less dense.

Likewise, the avatar gets smaller in the G.E.L. because the effect of a power-up ends. Since the reactor interacts like an enemy in the level, the avatar gets back to its normal size after being in contact with the reactor, with the intention to communicate that the stream gets less dense due to evaporation (Figs. 8 and 9). Even if learning is projected in the levels, some elements and interactions need to be explained, which is why the level presentation is part of the CHEM Jam in stage two.

This level was not given a 3 in creativity because the creators used some images provided as examples for the new items, e.g. mixers, pumps and flow indicators (Fig. 10). The authors consider that the levels would have been more creative if original pictures had been used.

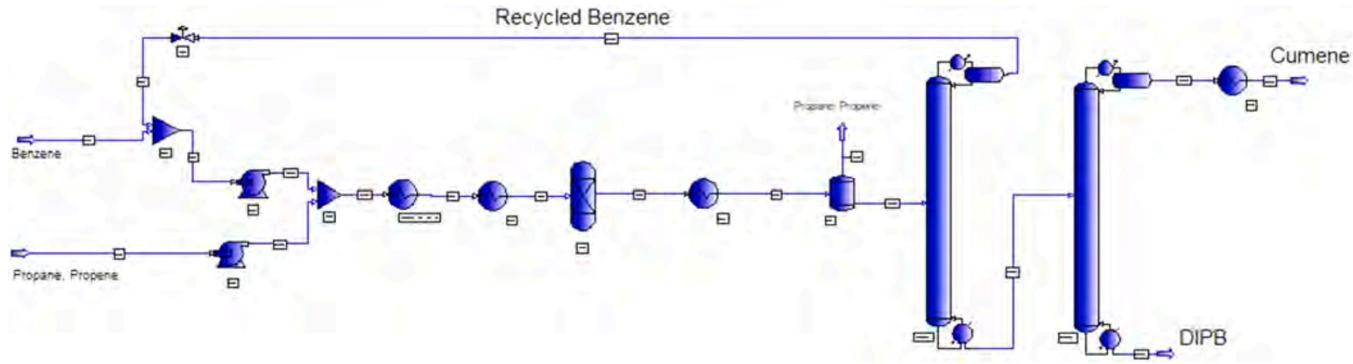

Fig. 6. The process flow diagram generated with the simulator PRO/II.

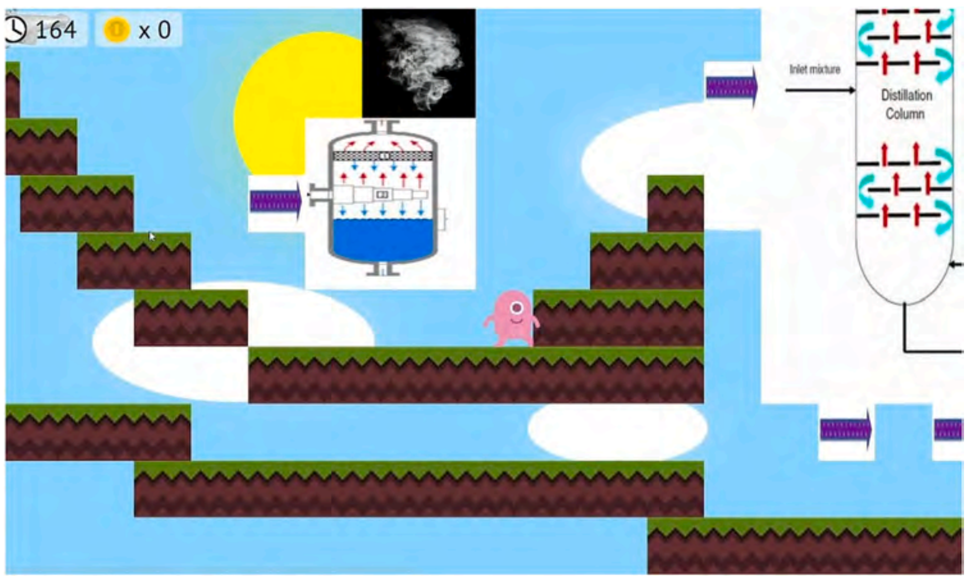

Fig. 7. Screenshot of part of the level showing two core unit operations: a flash tank on the left side of the screen and part of a distillation column on the right.

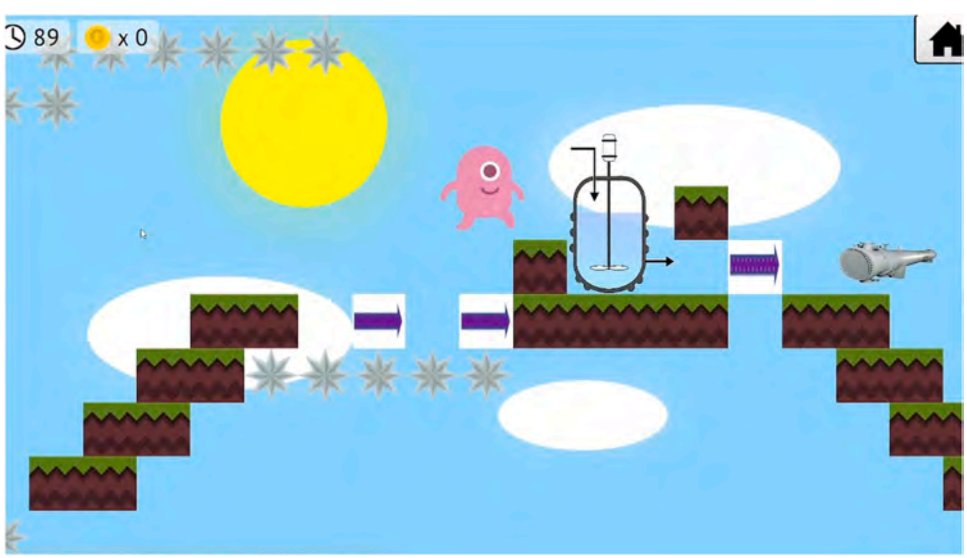

Fig. 8. Screenshot of the level with the oversized avatar before hitting the reactor (left) and back to normal size after being hit by the reactor (right).

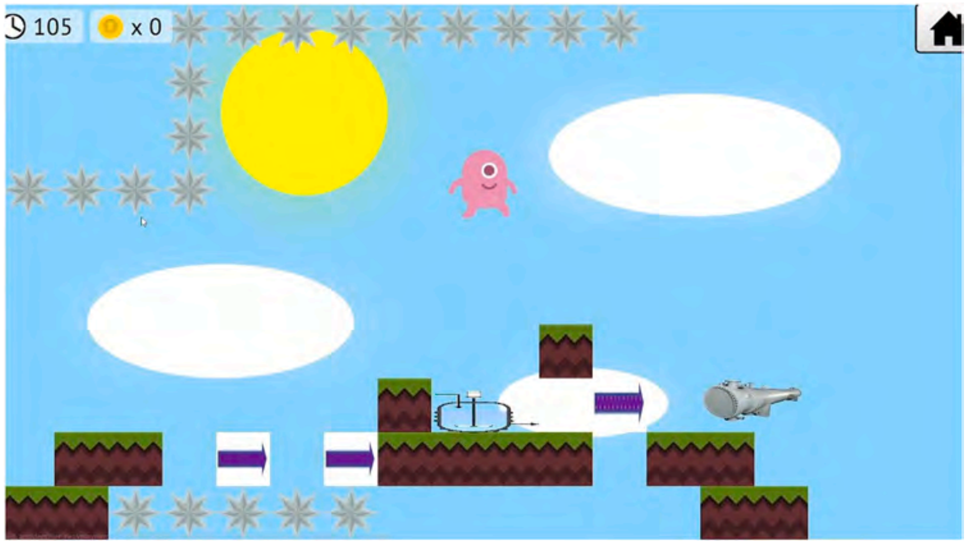

Fig. 9. Screenshot of the avatar back to normal size after hitting the reactor (left) and back to normal size after being hit by the reactor (right).

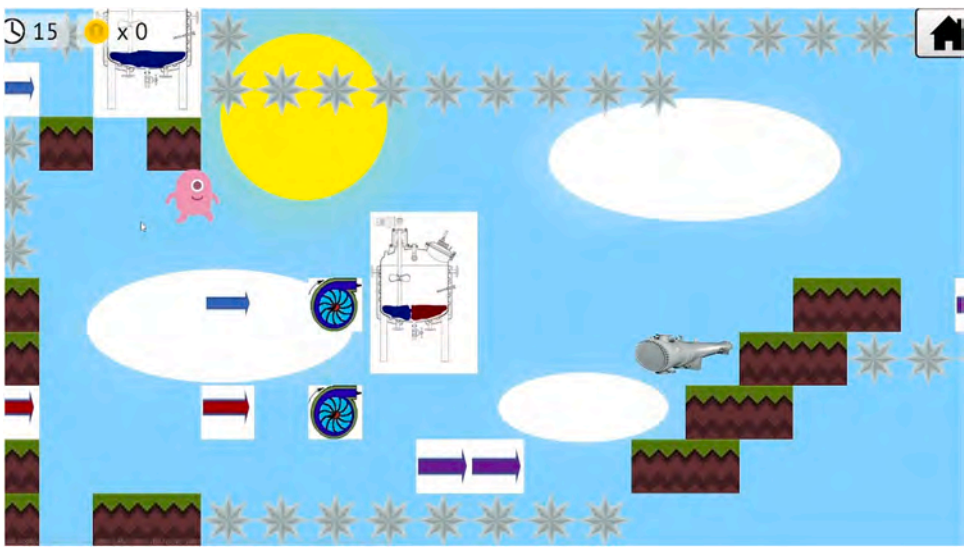

Fig. 10. The images used for the pumps, the mixers and the flow indicators in this picture were the same as the images used in the inspirational level.

4. Impressions

The Associate Professor and course manager of the process design course at DTU in which the CHEM Jam was integrated sent an email on 14.12.2021, after the oral exam, with his impressions about the CHEM Jam event:

> "The oral exam is group-based, and it had 12 groups (in total 48–49 students), among which 9 groups added the CHEM Jam part in their presentations. Some of them were impressive."

> "Overall, some improvements could be made for the CHEM Jam Game Editor, but it is a nice experience, and it would be very interesting to further study the integration of this platform in teaching, for example, in Spring 2022."

Considering that the CHEM Jam was an optional activity and that it was included in the course with very short notice, the participation rate was high, which shows the interest of students for this type of events.

The improvements the professor referred to in the second comment have to do with some minor bugs in the G.E.L., which have now been fixed in the Windows version of the editor. The event could not be held again in Spring 2022 due to availability issues.

5. Discussion

The G.E.L. is not intended to replace the functionality of process simulators, but to extend them. That is, in a process design course, students can use the simulators to solve design problems and create conceptual flow sheets. The CHEM Jam can be used subsequently, to present a thought-provoking challenge through which students can practice learning transfer.

The limitation of interactive behaviours in the G.E.L. is a crucial feature of the proposed activity. New behaviours could be added, related to, for example, chemical and physical phenomena, so that high-fidelity unit operations could be represented in the game levels. However, in an experience like the CHEM Jam, learning occurs mostly during the creation process, in an attempt to solve a challenge. If new interactive behaviours are integrated to ease the difficulty, it may have a negative effect as a learning experience. Therefore, this paper considers that the limitations of the G.E.L. to represent the learning content are part of the challenge and learning opportunity.

An extended version of the CHEM Jam could consist of integrating 3D work of the unit operations in the G.E.L. Such an extension would allow working more thoroughly with the unit operations, as well as integrating the CHEM Jam at an earlier stage of the course. In that case, the activity would facilitate the learning of the content as well as the practice through the game levels. This option would imply changing the 2D editor for a 3D platform editor, as well as increasing the complexity of the tool.

Even though game engines are technically more sophisticated than the G.E.L. and offer a great variety of features to make games, e.g. Unity, Unreal Engine or Game Maker Studio, using these tools involves going through a steep learning curve. That is the case particularly for users who do not have any programming knowledge. By using an intuitive tool like the G.E.L. in the CHEM Jam, participants can easily use the editor and focus on the challenge that is integrating process design elements in a platform game level.

Activities that promote learning transfer, i.e. the improvement of learning in a new task through the transfer of knowledge from a related task that has already been learned (Roque et al., 2016), especially in adult learners, are in the centre of educational research (Gee, 2005). When organised towards the end of the course, the CHEM Jam can facilitate a fitting setting in which new knowledge in game design is acquired, prior knowledge about chemical processes is applied, and new and prior knowledge are integrated in a platform game level for the benefit of learning.

The level creation is structured as a collaborative process because that is how the process design course at DTU is structured. But the CHEM Jam could be presented as an event during which the game levels are created individually. In that case, peer-to-peer interaction will be reduced mainly during that stage. However, some interaction will remain in the stage two through level presentations and feedback given by facilitators.

In recent years, new online platforms, e.g. CREY, Roblox or CORE Games, offer systems in which programming skills are not necessary to create a great variety of digital games. However, beyond making games, users of these platforms enjoy sharing their creations, receiving comments from other users, playing other users' games and inviting friends to play together. It is an empowering setting to create, share, learn and have fun.

Overall, this paper argues that engineering education would benefit to a great extend from integrating game creation events with the beneficial elements of game jams, such as the motivational effects of participating in an informal competition or creating within a limited timeframe. After the CHEM Jam's participation rate, the event is an example that these activities attract the attention of most students. This interest can be used to present an unconventional challenge through which learning occurs. That is making game levels can be used to convey students' expertise in chemical engineering as a practice of problem-solving skills through collaborative learning.

6. Conclusion

This paper argues that game-making activities should be integrated in curriculum- based education for STEM disciplines to reinforce how students learn in higher education. Learner-centred activities like game-making events can facilitate a setting in which learners experiment and explore to solve a problem.

On that basis, this paper aims to serve as example to align a game creation event with an engineering process design course. The structure of the event, named CHEM Jam, and the assessment methodology are described. The assessment framework has considered the learning objectives of the course to facilitate the integration. A link to download the custom-made Game Editor for Learning, a tutorial for first-time users, an assessment template and three game- play videos of levels examples are included in the supporting material section of this paper.

Finally, the CHEM Jam can inspire other teaching methodologies to improve engineering education by recreating practices of game-making creation events and communities.

Supporting Material

A free version of the desktop G.E.L. editor can be downloaded in this link: G.E.L. - Game Editor for Learning.

Additionally, the G.E.L.'s tutorial for first-time users (PDF document), an assessment template (Word document) and three gameplay videos of level examples (video files), are attached.

Declaration of competing interest

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

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