Towards an Assessment Framework for Learner-Created Game Levels in Chemical Engineering Education

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Abstract: Educational initiatives, which allow university students a considerable degree of agency in their learning, are receiving an increasing amount of academic attention. However, how to measure learner-driven experiences in terms of learning can be challenging. This study proposes a framework to assess qualitatively the platform game levels designed for an assignment in a chemical process design course. Students create levels for a digital game to facilitate knowledge about chemical processes. A pilot study is conducted with chemical engineering students, during which they are asked to create a level for a platform game with a custom-made editor. The resulting level, which is to represent a chemical engineering process of ammonia production, is coded and analysed to eventually provide an assessment methodology. After application in the pilot study, the assessment shows to be efficient, and results are discussed.

Keywords: platform games, generative learning, makerspaces, game jams, Higher Education, learning through game design, chemical engineering, qualitative assessment framework

1. Introduction

While scientific communities and educational practitioners have shown interest in approaches that offer a significant degree of agency to learners, how to measure learning during this sort of activities and incorporate them in curriculum-based education can be challenging. The present paper proposes a methodology to assess a new strategy based on chemical engineering students designing game levels for learning. The activity is framed in an informal and collaborative setting described hereafter, which takes students out of the conventional class, to explore other, novel learning approaches in engineering education.

2. Background and related work

One motivation of this educational initiative is to provide an environment in which students can apply and transfer their knowledge in another context, also called learning transfer (Hung, 2013, pp. 27-29), by emphasising learners' own exploration and experimentation (Audrey and Riley, 2018, pp. 2-4), as well as social interaction (Derry, 2013; Audrey and Riley, 2018, pp. 57-58). More precisely, Wittrock's work to apply generative learning in education (Wittrock, 2010; Fiorella and Mayer, 2016, p. 718) constitutes the baseline of the present study. His approach facilitates the grounds to integrate learner's prior knowledge with to-be-learnt information (Fiorella and Mayer, 2016, p. 720), which in the present activity is used in favour of knowledge application and transfer.

This study's approach sets out from the Maker Movement (Hatch, 2014; Martin, 2015; Weitze, 2018, p. 143), an extension of the Do-It-Yourself social trend (Schad and Jones, 2020). The Maker Movement can bring a series of benefits when applied to education (Fornós, 2020c). This kind of initiatives do not only involve creating an artifact, but also learning through the experience, using appropriate tools, sharing with the community and encouraging a playful approach to foster creativity. Research suggests (Kafai et al., 2014; Tofel-Grehl et al., 2017; Burton et al., 2018) that maker-centred learning can attract learners to STEM subjects (Lacey, 2010; Martin, 2015; Schad and Jones, 2020) by offering a safe hands-on setting. An example is illustrated by a mission to Mars project (Burton et al., 2018), through which students actualize mathematical principles in the production of a rocket (Burton et al., 2018; Schad and Jones, 2020; Fornós, 2020c).

Events to create games are the source of inspiration for the present study, which investigates a game jam for learning in chemical engineering. Game jams are accelerated events of game creation (Kultima, 2015) that have gained popularity in the recent years (Meriläinen, 2019, p. 30). While game jams share most of the previously mentioned makerspaces' benefits, some features are distinctive to game jams and directly related to this investigation.

Game jammers are mainly motivated by learning (Preston et al. 2012) or networking (Fowler, 2016), which occurs under unconventional conditions. Since the events are normally held during weekends or spare time, game jams are associated with informal spaces primary organised for enjoyment. Moreover, the events represent unique opportunities to gather multidisciplinary teams typically comprised of computer scientists, game designers, artists and game enthusiasts who would rarely coincide otherwise (Meriläinen, 2019, pp. 31-32). Finally, a winning team is designated at the end of the event, which adds a competitive aspect in the experience.

By offering a learning strategy within a game jam concept, this study presents a cooperative and informal environment out of what chemical engineering students are used to. In this new learning model, participants take on the role of game designers to create game levels about chemical processes. Through their new leading role, students explore and create their own learning experiences to integrate prior knowledge in chemical processes in a different context. Not only is knowledge transfer effective, but also reflection upon the learning content is triggered. Furthermore, the activity introduces game design to an unusual audience, chemical engineering students, who can contribute to the game industry by providing different ideas and perspectives.

3. Present study

The present investigation aims to develop an assessment framework applicable to platform game levels created during a game jam for chemical engineering students, named CHEM Jam (Fornós, 2020a; Fornós, 2020b). To this end, this paper begins by describing the CHEM Jam's learning strategy, presenting the custom-made editor and analysing the pilot study.

3.1 Learning strategy

The learning strategy employed in the CHEM Jam sets out from Michelene T. H. Chi's ICAP model (Chi, 2009; Chi and Wylie, 2014; Fiorella and Mayer, 2016, p. 719-720), which is structured in four modes of engagement, namely *passive*, *active*, *constructive* and *interactive*. Each mode of engagement corresponds to different types of learner's behaviours and learning processes as described in figure 1 (Chi and Wylie, 2014, p. 220).

	PASSIVE *Receiving*	ACTIVE *Manipulating*	CONSTRUCTIVE *Generating*	INTERACTIVE *Dialoguing*
LISTENING to a lecture	Listening without doing anything else but oriented toward instruction	Repeating or rehearsing; Copying solution steps; Taking verbatim notes	Reflecting out-loud; Drawing concept maps; Asking questions	Defending and arguing a position in dyads or small group
READING a text	Reading entire text passages silently/aloud without doing anything else	Underlining or highlighting; Summarizing by copy-and-delete	Self-explaining; Integrating across texts; Taking notes in one's own words	Asking and answering comprehension questions with a partner
OBSERVING a video	Watching the video without doing anything else	Manipulating the tape by pausing, playing, fast-forward, rewind	Explaining concepts in the video; Comparing and contrasting to prior knowledge or other materials	Debating with a peer about the justifications; Discussing similarities & differences

Fig 1: The four modes of engagement in the ICAP Framework (Chi and Wylie, 2014, p. 221).

The CHEM Jam is a learning experience structured in four stages, during which the four modes of engagement occur as shown in fig. 2.

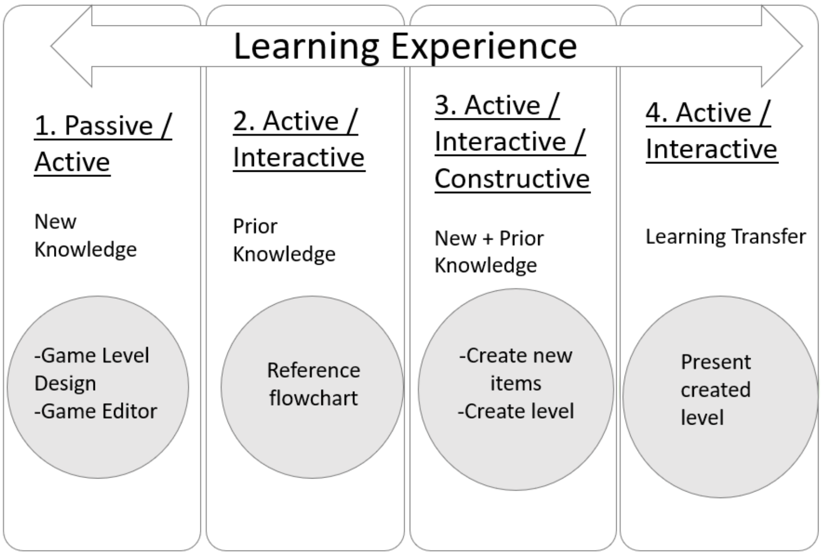

Fig. 2: The learning strategy for the CHEM Jam.

This structure facilitates a process through which new knowledge about game design is acquired, prior knowledge about chemical processes is applied, and new and prior knowledge are integrated in a platform game level to eventually ensure learning transfer. The type of transfer occurring during the CHEM Jam may be classified by experts as *far transfer* (Hung, 2013, p. 29). *Far transfer*, as opposed to *near transfer*, refers to a low degree of similarity and pragmatic relevance between the original context in which knowledge was learnt and the new context in which the prior knowledge is applied.

Since far transfer involves more complex levels of cognitive processes than near transfer, the former poses usually more challenges too. Hence, the CHEM Jam must offer minimal guidance, mainly in form of an example and the theme of the event, to guarantee that transfer of knowledge occurs. Even if instructional elements may limit some creativity aspects of the activity, these elements are essential for students to understand their task and so they are strictly necessary.

Following Chi's framework, learning in the CHEM Jam begins with a passive mode to introduce the new knowledge to participants through a game level design lecture. Next, participants test the custom-made editor, so they are using a software, which is an activity comparable to manipulating a videotape in figure 1, hence an active mode of learning occurs.

In the second stage of the CHEM Jam, participants are introduced to the theme of the event. The theme involves a chemical engineering process, e. g. industrial production of ammonia. Participants discuss and select with peers the reference flowchart, representative of the event's theme, that will help them create a platform game level later (fig. 3).

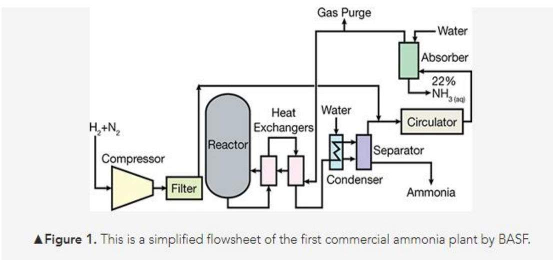

Fig. 3: Example of a flowchart representing how ammonia can be produced on industrial scale.

Due to time restriction and that the game level remains the focus of the activity, an open access image can be used for the flowchart, provided the image reflects a real and effective chemical production process. Both active and interactive modes are present simultaneously in this stage, which requires learners' prior knowledge in chemical engineering processes. Therefore, the CHEM Jam is intended for chemical engineering students who have knowledge in chemical reactions and processes and can be ideally planned as an assignment of a chemical process design course. As some researchers argue, minimal guidance starts to be effective when learners can provide internal guidance (Kirschner et al, 2006), which occurs when learners have sufficient prior knowledge. And so should have participants in the CHEM Jam for an effective experience.

During the third stage, participants use the selected flowchart to create new game items for the level. After that, the game level is created by combining new and existing items with the custom-made editor as explained in more detail hereafter. In order to decide which game items are necessary and how to structure the platform game level, participants must integrate new and prior knowledge. Active, interactive and constructive behaviours are therefore needed in this stage.

The final stage comprises the participants' presentation and explanation of the created level in front of their peers, including comments, questions and discussion. In this stage, active and interactive modes are combined and learning transfer is effective through the creation and explanation of a chemical-engineering- based game level (Hung, 2013, p. 27).

3.2 Game editor's features

The G.E.L., Game Editor for Learning, 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 mobile open-sourced Felgo's Level Editor for Platformers.

Platformers or platform games are a type of action game (Apperley, 2006) in which typically the main character or avatar, controlled by the player, must run and jump to avoid obstacles and/or defeat enemies (Minkikinen, 2016; Fornós, 2020b). Platform game editors allow to create, play and share levels of this kind of games, usually by dragging and dropping existing game items in the level (fig. 4).

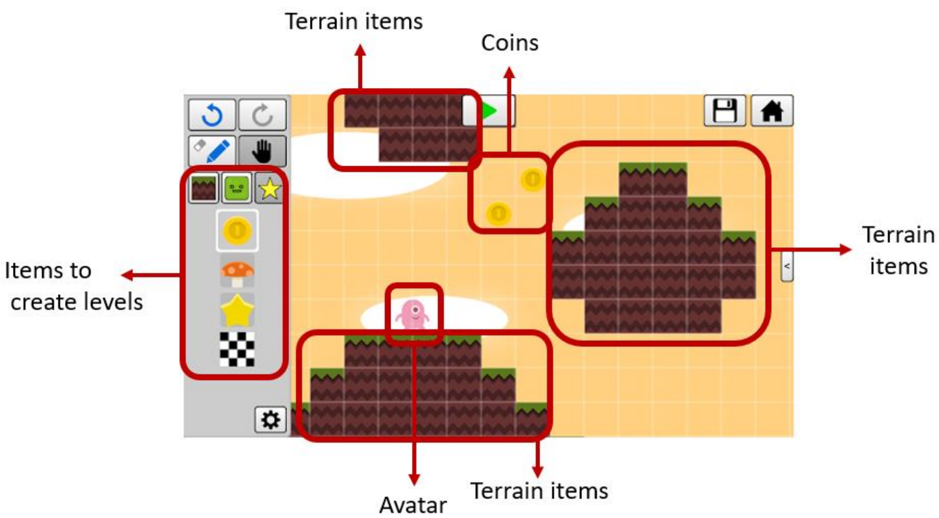

Fig. 4: Creation screen with a level example in Felgo's Level Editor

For more information about platform game editors, please refer to the paper "*Super Mario Maker 2* as a Tool for Educational Game Design" (Fornós, 2020b).

The main feature of the G.E.L. is that users can choose chemical-engineering-related images, with which new game items can be skinned, and combine them with the existing items (table 1) for their creations.

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)	

Table 1: Existing game items in the Game Editor for Learning including category, type, interaction and feedback in the gameplay.

New game items created with the G.E.L. will show the appearance of the image selected and will be assigned one of the items type in table 2. 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 chemical engineering processes. For example, a flash tank could interact like an enemy jumper, which means that the avatar, controlled by the player, will die if it gets in contact.

This feature allows users to integrate chemical-engineering-looking items in a platformer game to decrease the activity's level of abstraction. A previous study conducted with Felgo's original editor showed some participants' frustration to complete the levels, mainly due to the high degree of abstraction between usual platform game editors without skinned items and chemical engineering.

3.3 Pilot study

The pilot study was conducted online with two master's students in chemical engineering from KU Leuven (Belgium) on a two-day event in February 2021. The first day, participants attended stages one, two and three of the CHEM Jam. The second day, students presented and explained the level that they had created with the G.E.L. Even with a small sample, the approach chosen produces thorough data to consider an efficient assessment methodology after examining the results qualitatively. Given these circumstances and the increased complications to attract students to voluntary online tests during the pandemic, a larger scale study is planned for a later study.

The theme of the pilot study was ammonia. Participants were given a mathematical problem about a chemical reaction resulting in ammonia and were asked to project the result of the problem in a game level in a creative way. However, participants ignored the mathematical equations and decided to base their level on the production of ammonia at industrial scale.

To ease the creation process, participants were offered a level example with a 3-step guide: select a flowchart representative of the proposed theme (fig. 3, for example), choose the skin or appearance of the new game items (fig. 5), assign item's types to the new items according to table 2 and finally combine existing and new items to create the level (fig. 6).

Fig. 5: Examples of new items' skins representing equipment necessary for industrial ammonia production: compressor, filter and reactor.

Fig. 6: Image of the level example provided during the pilot sutdy showing existing and new items, as well as the avatar in pink.

As described in table 1, game items can interact differently. These interactions may show positive, negative or neutral feedback, depending on whether the interaction rewards, punishes or does not influence the gameplay respectively. Hence, the interactions can be used as means of communication with players in the levels.

3.4 Pilot study's results

The level created during the pilot study showed a combination of physical phenomena and equipment required in the chemical reaction for ammonia production. More specifically, the elements represented were pressure, catalysts, reaction vessel, temperature and ammonia finally applied as fertilizer after production.

The sections about pressure (fig. 7), catalysts (fig. 8) and temperature were represented with two game items each that showed opposed behaviours in the gameplay.

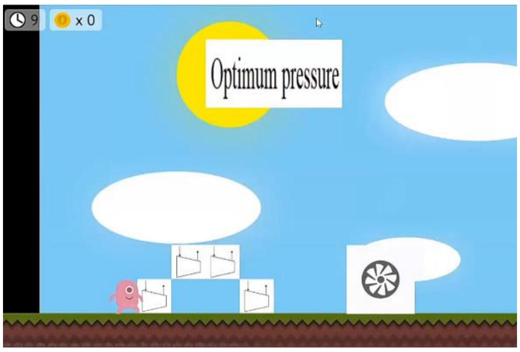

Fig. 7: Pressure represented in the resulting level.

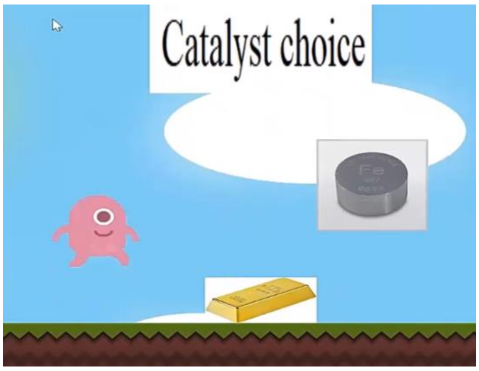

Fig. 8: The catalyst phase represented in the resulting level.

For example, in the pressure section, compressors were assigned a coin interaction and the turbine acted as an enemy. Thus, the avatar is supposed to collect the compressors, but to avoid or kill the turbine to progress in the level.

3.5 Qualitative thematic analysis

The data source is a recorded video in which participants are conducting the stage four of the activity, i.e. they share and explain in a conference call the level that they created. For the qualitative analysis, the resulting level was coded with ATLAS.ti (Muhr, 1991), a program designed for qualitative thematic analysis, and figure 9 was produced as a result.

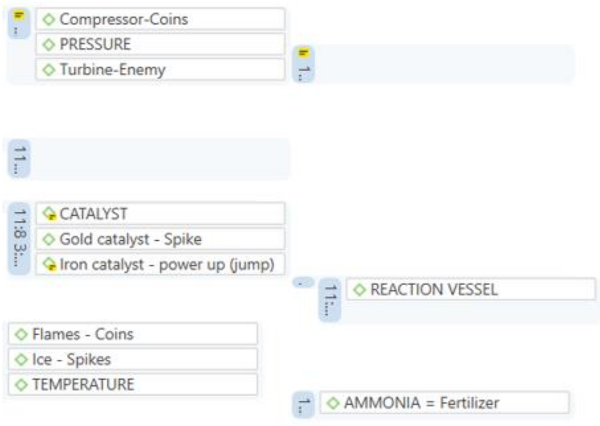

Fig. 9: Codes found in the level's thematic analysis with ATLAS.ti.

The pressure, catalyst and temperature phases in the level include game items rewarding or punishing the player behaviour to provide information about what should occur for the chemical reaction to happen.

For instance, the player will know that the compressor in the pressure section is a positive asset for the reaction, because the compressor turns into coins when the avatar gets in contact. However, the turbine behaves like an enemy, and the avatar gets hurt if it passes close by. Through this section, the level creators want to inform that, on one hand, compressors increase pressure, which is required for the chemical reaction. Turbines, on the other hand, make pressure to decrease and represent an obstacle for the reaction. In sum, the thematic analysis allows to identify the pattern in fig. 10.

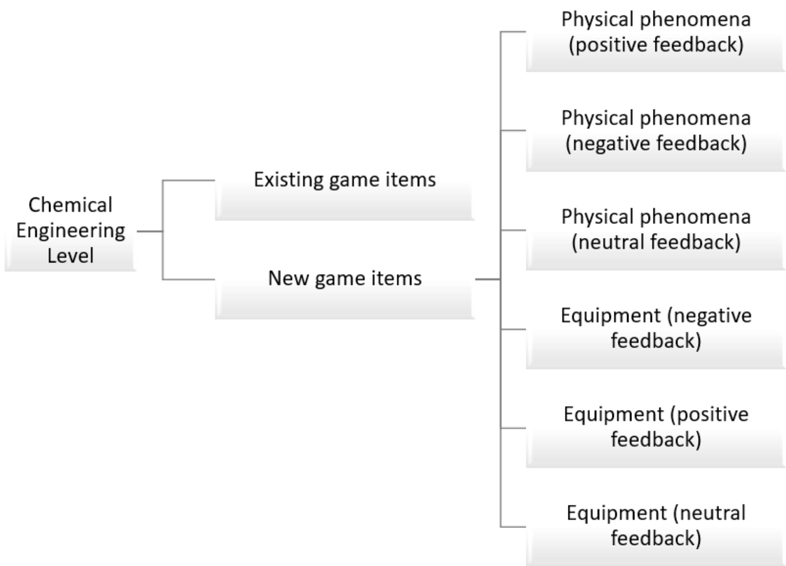

Fig. 10: Pattern identified after coding the level.

It is identified that physical phenomena and equipment involved in chemical engineering processes can be used to skin the game items in the levels. The pattern also shows that game items communicate relevant information of chemical processes through the item's feedback in the gameplay, which is positive, negative or neutral. Therefore, in the activity, flowcharts provide visual information about industrial equipment, physical phenomena and how they interact during chemical engineering process that, together with learner's prior knowledge, support the creation and structure of platform game levels.

4. Assessment framework

In learner-driven activities like the CHEM Jam, the pre/post-test, constructive alignment and other models based on intended learning outcomes have proved to be ineffective to measure learning due to the creative nature of this sort of activities. Instead, this study measures learners' understanding through the lens of the artefact created during the experience. In other words, the assessment analyses how learning is applied and transferred in the resulting platform game level. In view of the complexity of the transfer, however, the assessment is not applied to the level in isolation and the presentation by their creators in the stage 4 of the CHEM Jam is considered for assessment purposes.

The assessment proposed in this study originates from the similarities between the way in which information is displayed in flowcharts and how the information is presented in concept maps. Concept mapping is a methodology benefiting teaching, learning and assessment practices in higher education (Novak, 1990, pp. 937-949; Brüssow and Wilkinson, 2007; McNeese and Reddy, 2015). A common feature of flowcharts and concept maps, relevant to the present investigation, is the capacity to show the concept's interconnectivity such as hierarchies, groups or sequences.

Given the mentioned similarity and how the resulting level relates to engineering flowcharts, Brüssow and Wilkinson's framework to assess concept mapping activities (2007) can be a suitable methodology to assess qualitatively this type of game levels. This methodology is based on providing feedback in line with certain criteria, which has been modified for the purpose of this study in table 2.

Criteria	Explanation
Accuracy	Content is factually correct
Utility	The practise is relevant for a chemical process design course
Clarity	The structure and the content knowledge are clear
Integration and complexity	The level reflects the complexity of chemical processes
Organisation	The level reflects the logic flows and relationships of phenomena/equipment graphically and visually
Creativity	The extent to which creative ideas and creative structures to represent content are used

Table 2: Assessment framework for the CHEM Jam.

This investigation presents a qualitative framework that grades the game levels and their explanations in terms of accuracy, utility, clarity, integration and complexity, organisation and creativity.

The category *accuracy* assesses if the learning content employed during the experience is correct, limited, incorrect or simply missing by giving a 3, 2, 1 or 0 score respectively (table 3).

ASSESSMENT SCALE	
3	Achieved
2	Correct but limited
1	Needs revision
0	Not included

Table 3: Scale to assess the game levels.

Utility can be used to grade to what extent the level is relevant for a chemical process design course following the same assessment scale as the previous category, as it is the case for all the categories in this methodology. The grade on how clear the content involved in the level was, is considered in the category *clarity*. Next, *integration* and *complexity* measure the level of difficulty of the content employed and how this is integrated with the resulting level. If the information is presented in a structured and logical manner in chemical engineering processes can be graded in the category named *organisation*. Finally, the last category *creativity* evaluates the degree of creativity of the ideas and structures used to represent the learning content.

4.1 Assessment of the pilot study

The proposed framework was applied to the pilot study´s results. Five PhD students with a chemical or chemical engineering background analysed the recorded video during which the game level is presented and explained. Assessors followed the criteria and scores described in table 2 and 3 for their assessments.

The results show that this methodology allows to efficiently provide feedback about the artefacts created during the CHEM Jam from a chemical engineering perspective (table 4).

Criteria	Achieved (3)	Correct but limited (2)	Needs revision (1)	Not included (0)
Accuracy	1	3	1	0
Utility	3	0	0	2
Clarity	3	2	1	0
Integration and complexity	2	2	1	0
Organisation	2	2	0	1
Creativity	5	0	0	0

Table 4: Grades given to the pilot study's level.

It is observed that assessors considered most categories to be either "Achieved" or "Correct but limited". The category *creativity* received a unanimous score of "Achieved". However, two assessors agreed that the category *utility* was not included in the experience. When this issue was explored in more detail, it showed a faulty definition of the category as referring to whether "the content is applicable to real life". This definition turned out to be too broad and misleading, which is why it was corrected as in table 2 to evaluate whether the experience is relevant for a chemical process design course. Finally, the grades of one of the assessors were based on the resulting level in isolation. So, he wrongly discarded the explanations given during the presentation of the level, which are essential for understanding crucial elements and without which learning outcomes are incomplete. As a result, his scores ranged from "Need revision" to "Not included" only.

5. Discussion

The results show that participants successfully presented a platform level that showed their expertise in chemical engineering in a creative way. Thus, the activity can be part of an engineering course to foster collaborative learning, reflection and creativity. Learning transfer is also encouraged by applying chemical engineering content in a game. Besides, the degree of complexity of the CHEM Jam is flexible and can be easily integrated in the Chemical Engineering curriculum. For instance, the activity can propose participants to create their own flowchart or using one produced in a previous class, typically as part of a chemical process design course.

Previous studies have highlighted the challenges to measure learning in game jams (Arya at al., 2013; Hrehovcsik et al., 2016; Meriläinen, 2018, p. 33), which also applies to most of generative learning practises. However, the assessment framework presented in this paper resolves two main issues. Firstly, the framework demonstrates not only that learning in chemical engineering processes occurs during a CHEM Jam, but also that learning can be increased by providing constructive feedback. Secondly, the criteria system for assessment will be introduced to CHEM Jam participants beforehand, which will guide learners in their creations without putting the explorative aspects of the experience into risk.

Flowcharts offer students the starting point to represent their levels in terms of structure and new game items. However, how interactions are assigned and used in the gameplay is open to interpretation. In this respect, chemical engineering students enjoy the freedom to explore new ways and be creative to some extent. They can come up with new interpretations of their expertise in a platform game level with their peers, which brings altogether an unconventional learning framework in engineering education that deserves further research.

6. Conclusion

A pilot study of the CHEM Jam, a game jam for chemical engineering students, was conducted in February 2021. Participants created a platform game level with a custom-made editor. The level showed physical phenomena and equipment required for a chemical reaction to produce ammonia at industrial scale. After analysis, a framework is created to assess this kind of game levels. The framework is applied to the resulting level of the pilot study and shows to be efficient. A CHEM Jam is planned, which resulting levels will be assessed by the methodology proposed in this study.

7. Future directions

The assessment framework proposed in this study will be used to assess the resulting levels of an upcoming CHEM Jam event, in which a significant number of participants will take part. During the event, the cognitive and motivational outcomes, as well as other unintended effects of applying this informal learning strategy, will be object of study.

Future research should consider the implications of the CHEM Jam in multidisciplinary teams. An accelerated event intended to create serious games could be organised among computer scientists, game designers, artists and engineers.

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Ludography:

Level Editor for Platformers (Felgo, 2016)

G.E.L. - Game Editor for Learning (Sílvia Fornós & Einar Klarlund, 2021)

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