Students making games as a learning strategy for chemical engineering

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This dissertation is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy (Ph.D.) at the IT University of Copenhagen

August 2022

This project has received funding from the European Union's EU Framework Programme for Research and Innovation Horizon 2020 under Grant Agreement No 812716.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor, Daniel Cermak-Sassenrath for agreeing to supervise this dissertation and for the trust he has shown in me. The Ph.D. voyage can be bumpy at times but I am deeply grateful that, under his supervision, I could enjoy the necessary freedom and independence to grow as an aspiring scholar.

I am also grateful for all the professional support received from my colleagues in the CHARMING (Chemical Engineering Immersive Network) project, especially from the fruitful conversations held during our regular Work Package 2 meetings with Jessica Dominguez Alfaro, Serkan Solmaz, Pedro Santos, Yuanyuan Hu, and Chioma Udeozor about chemistry, chemical engineering, educational science, games, technology, and much more.

Special thanks to all the members of the Center for Computer Games Research, now called the Center for Digital Play, at IT University of Copenhagen, in particular to Nina Croitoru, Nina Patricia Houe, Miruna Vozaru, Dom Ford, Hanna Wirman, Hans-Joachim Backe, Torill Mortensen, Martin Pichlmair, and Miguel Sicart for their precious feedback and help.

I would like to extend my sincere thanks to Einar Klarlund for his collaboration in programming the Game Editor for Learning, a custom-made tool essential for the present investigation.

I would like to warmly thank Patrick Helmenkamp Achen, Deborah Carberry, Xiaodong Liang, Seyed Soheil Mansouri, Ulrich Krühne, Simoneta Caño de las Heras and all participants or personnel involved in the intervention during a mandatory course in the Department of Chemical and Biochemical Engineering at Danmarks Tekniske Universitet in Autumn 2021.

I would be remiss in not mentioning the Ph.D. School for their overall support.

Finally, I could not have undertaken this journey without my friends and family, including my partner Morten and my two cats, who supported me emotionally during these three years and a half.

RESUMÉ

Det er almindelig praksis at udvikle computerspil for at lære at designe eller programmere computerspil på videregående uddannelser. Her er hypotesen imidlertid, at processen med at udvikle spil – ud over de spil- eller programmeringsmæssige færdigheder, det giver – udgør en læringstilgang, som kan tjene som en udvidelse af den pensumbaserede undervisning inden for forskellige emneområder. Hvis vi arbejder videre med den hypotese, udfordrer den læringsaktivitet, der foreslås i denne undersøgelse, de studerende til at designe spil, hvorigennem deres tekniske ekspertise kommunikeres. De studerende øver sig i at håndtere en udfordring, som især er relevant for at kunne tænke kritisk og foreslå innovative løsninger inden for STEM-disciplinerne (videnskab, teknologi, teknik og matematik).

Der er to formål med denne undersøgelse. Undersøgelsen tager først og fremmest udgangspunkt i de vigtigste søjler, der skal til for at integrere en spiludviklingsevent i pensummet på civilingeniørstudiet, dvs. læringstilgang, værktøjer og kontekst. Sekundært udforsker

undersøgelsen konsekvenserne af, at de studerende udvikler spil på et ingeniørstudium med fokus på primært kognitive, motiverende og sociale konsekvenser.

I førskoleundervisningen lærer små børn gennem leg med legetøj. Det gør de blandt andet med byggeklodser, typisk fremstillet af træ, som er ret populære i børnehaver. Klodserne er inspirerende visuelle elementer, som børnene bruger til at skabe og lære i processen. Små børn observerer disse blokke for at reflektere over, hvad de kan skabe, og hvordan klodserne kan kombineres for at nå det ønskede resultat. På samme måde anbefaler denne undersøgelse en visuel spileditor til unge voksne, så de kan lære af processen med at designe spil på en videregående uddannelse. Med afsæt i en tilgang med fokus på de studerende får de studerende rollen som spildesignere, så de opnår en højere grad af autonomi i læringsprocessen. Læringen sker ved, at de studerende selv udforsker og eksperimenterer med at udvikle et spil frem for at følge instrukser. Den konceptuelle tilgang bygger på ideer fra Seymour Paperts konstruktionisme, som udvider konstruktivistiske teorier, idet de studerende – ud over at skabe deres egen viden – skaber et digitalt game level. Da spilskabere har behov for at dele deres kreationer og interagere med hinanden, kan læringsoplevelsen forbedres.

Der er udviklet en game level editor til brug for undersøgelsen. Game Editor for Learning (G.E.L.) er et redigeringsværktøj specialudviklet til denne undersøgelse med inspiration fra game level editors til 2D træk- og slip-platforme. Ud over allerede udviklede spilelementer til oprettelse af levels indeholder G.E.L. en funktion, der gør det muligt at overføre 2D-billeder, hvorigennem nye spilelementer kan genereres og bruges som skins. Med denne funktion gør editoren det muligt for dem, der ikke er spildesignere, at integrere teknisk indhold i deres arbejde og, vigtigst af alt, reflektere over, hvordan indholdet skal integreres i spilelementer og -mekanismer som led i læringsprocessen.

Denne undersøgelse bidrager også med en uddannelsesmæssig tilgang i tråd med kulturelle trends. Mere konkret er den specifikke læringsoplevelse kaldet CHEM Jam en samarbejdsevent kendt som game jam i forbindelse med spilstudier. Game jams er hackathon-lignende events, hvor spil udvikles i løbet af forholdsvis kort tid. Hackathons og game jam-events kan tiltrække deltagere og få dem til at engagere sig kognitivt og socialt omkring skabelsesprocessen. Det hævdes imidlertid, at game jams, til forskel for andre former for hackathons, grundlæggende er et spil med henblik på at udvikle spil, og har den ekstra fordel, at de engagerer deltagerne på en legefuld måde. I sidste del af undersøgelsen adresseres konsekvenserne af at udføre en CHEM Jam, som svarede til et designkursus på en bacheloruddannelse i efteråret 2021. I interventionsprocessen udviklede de civilingeniørstuderende game levels med G.E.L. til læringsformål.

Overordnet har denne tværfaglige undersøgelse til hensigt at bidrage til området for spilstudier, undervisningsbrug og ingeniøruddannelser. Særligt undervisere inden for ingeniørvidenskabelige discipliner vil kunne bruge denne bog som inspiration til at integrere en aktivitet med fokus på studerendes spilskabelse i deres forelæsninger eller undervisning.

ABSTRACT

Making games is a common practice to learn game design or programming in higher education. However, here it is hypothesised that beyond game-related or programming skills, the process of making games represents a learning approach that can extend curriculum-based education in different subject areas. Drawing on that hypothesis, the learning activity proposed in this study challenges students to design games through which their expertise in chemical engineering is communicated. Learners practice how to deal with a challenge, which is particularly relevant to thinking critically and proposing innovative solutions in STEM (Science, Technology, Engineering, and Mathematics) disciplines.

The aim of the present study is twofold. Firstly, the investigation is centred on the main pillars required to integrate a game creation event into the chemical engineering curriculum, i.e. learning approach, tools, and context. Secondly, this research explores the implications of students making games in an engineering course, mainly focused on cognitive, motivational, and social outcomes.

In pre-school education, infants learn by playing with toys. Among those toys, building blocks typically done out of wood are quite popular in kindergartens. These blocks are inspiring, visual elements to create and learn during the creation process. Infants observe those blocks to reflect on what can be created and how the blocks could be combined to attain the desired outcome. Similarly, this investigation proposes a visual game editor for young adults to learn from the game design process in higher education. In this design-based research, students take on the role of game designers as a student-centred approach in which students enjoy a high degree of autonomy during the learning experience. Learning occurs as students explore and experiment by themselves to create a game, instead of following instructions. The conceptual approach builds on ideas of Seymour Papert's constructionism, which extends constructivist theories because, besides creating their own knowledge, students create a digital game level. Since creators feel the need to share their creations and interact with others, the learning experience can be improved.

To facilitate the study's investigation, a game level editor has been developed. The Game Editor for Learning (G.E.L.) is a custom-made editing tool for the present study, which has been inspired by 2D drag-and-drop platform game level editors. In addition to the pre-made game items to create levels, the G.E.L. includes a feature to upload 2D pictures, through which new game items can be skinned. With that feature, the editor allows non-game designers to integrate engineering-related content in their creations and, most importantly, to reflect on how the content should be integrated with the different game elements and mechanics, as part of the learning process.

An additional contribution to this investigation is offering an educational context that echoes cultural trends. More precisely, the specific learning experience, named CHEM Jam, is a collaborative event known as game jam in game studies. Game jams are hackathon-like events to create games in a relatively short period of time. Hackathons and game jam events can attract participants and engage them cognitively and socially around the creation process. However, it is argued that game jams, unlike other types of hackathons, are fundamentally a game to make games and, as such, have the added advantage to engage participants playfully. In the final part, the present study addresses the implications of conducting a CHEM Jam, which was aligned with an undergraduate process design course in Autumn 2021. During the intervention, chemical engineering students created game levels with the G.E.L. for learning.

Overall, this interdisciplinary investigation aims to contribute to the fields of game studies, educational science, and engineering education. Particularly educational practitioners in engineering disciplines may find in this book an inspirational source to integrate a learner-centred activity, with game making at its core, in their lectures or teaching.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

INTRODUCTION

My desire to embark on the journey to write a doctoral dissertation emerged after an eye-opening experience as an external lecturer at TecnoCampus (Universitat Pompeu Fabra, Barcelona, Spain). During the academic years 2014-2015 and 2015-2016, I set up and taught an unconventional EFL (English as a foreign language) course, as part of a recently established undergraduate degree in game design and production. The activities included in the curriculum spanned from discussions about sophisticated game plots, usually selected from their favorite games, to creating *Let's Play* videos, i.e. videos of students playing a game that were commented on by the students themselves in English.

Despite minor issues due to my lack of lecturing experience, I enjoyed teaching that course very much. I realised that the learning approach of the course was my first attempt at efficiently framing my previous knowledge and experience in games within another context since I was using games and game culture to teach English. Beyond the course activities, I had the impression that the connections between games and learning were endless, and my desire to delve deeper into those connections grew to the point that I ended up writing this doctoral dissertation.

1.1 Background

Digital games as a communication channel introduce new affordances compared to other media, such as movies or books, that turn games into unique opportunities from a learning perspective. Playing a game often implies learning new skills, attitudes, or behaviors that challenge players. To win or progress in a game, players may need to think critically, explore, experiment, or even create, depending on the type of game (Ching, 2012, pp. 767-768). Moved principally by games' behavioural and attitudinal effects on players, scientists and practitioners began to consider how to leverage games' potential for good in other contexts than entertainment, e.g. for educative purposes (Gee, 2003; Squire, 2003; Shaffer et al., 2005).

Using games for learning became widely spread after a paradigm shift in the socio-cultural perception of games, initiated by the increasing use of mobile phones and social media in the early 2000s (Juul, 2010; Leaver and Willson, 2016). The emergence of a network society, including its increasingly progressing technologies (Castells, 2010), has revolutionised the way we communicate and, more specifically, how we consume games. These digital artifacts attract now a wider audience beyond the stereotypical player we were accustomed to in earlier years (Shaw, 2012; Chess, 2014; Arnseth et al., 2018, pp. 6-7), which has stimulated the application of games or game-related elements in other contexts than entertainment.

The digital revolution re-formulated our understanding of higher education, resulting in an emerging type of university. The new concept, also called Mode 3 university (Matthews, 2021; Carayannis et al., 2018) is defined by Nørgård et al. (2019, p. 75) as a university that "configures itself as an open network entangled in and connecting with other networks, enabling citizens, professionals, workers, researchers, teachers, students, and whoever is interested and engaged in the networks to think, talk and tinker together."

It is assumed that such a network university calls, among other things, for transversal studies that connect interdisciplinary fields to discuss, create, and learn collaboratively. This doctoral dissertation sets out from that statement to bring together the fields of game studies, educational science, and chemical engineering, in this particular order. That is, this investigation begins analysing what games are and how games have been approached to inspire new, effective learning methods in the last decades.

Games are complex interactive artifacts that can be approached from a wide variety of angles. Since the industry is constantly innovating and evolving, finding a canonical definition of a game is a foundational issue in game studies (Stenros, 2017). Similarly, a concise taxonomy of game genres, which would ease game analysis and understanding of games to a great extent, is to date also a contested matter (Apperley, 2006; Clarke et al., 2017).

For example, a game can offer single player or multiplayer experiences, depending on the number of players that are sharing the same game experience. The game *World of Warcraft* (Blizzard, 2004) can be defined as an MMO (Massive Multiplayer Online) game. Typically, MMOs are played online with other players, some of which are allies and some others, opponents (Ducheneaut et al., 2006).

The *Mario Kart* (Nintendo, 1992) game, for instance, is a competitive type of game because players, who are driving customised vehicles on various racing tracks, must beat the other players and win the race (Bosboom et al., 2016). On the other hand, *It Takes Two* (Hazelight Studios, 2021) is a cooperative game in which two players must work collaboratively, defeating enemies and solving puzzles, to progress in the game.

Some education practitioners support the use of commercial games as powerful engaging tools for learning. Commercial games are defined in this thesis as mainstream games that present entertainment, enjoyment, or fun as a primary purpose. The *Assassin's Creed* series (Ubisoft, 2016) represents an example of how commercial games can be used for learning. Thanks to accurate data of real historical facts included in the games, this action game series can be an effective tool in a history class for learning about ancient Egypt or the French revolution depending on the episode (Schrier, 2019, pp. 32-38).

Papers, Please (3909, 2013) is a single-player game consisting in playing as an employee in a refugee checkpoint. The player needs to be paid to feed and keep their family healthy, which means that the work assigned must be performed correctly.

During their duties, the player is confronted with political and ethical decisions about, for instance, accepting or not bribes to approve the entrance of immigrants. Overall, as mentioned in Schrier's anthology (2019, pp. 279-282), including 100 games to use for learning, *Papers, Please* provides the grounds to commit students to economical, political, and ethical issues.

Other educational practitioners advocate for using educational games for learning instead of commercial games. Serious or educational games refer to "games that do not have entertainment, enjoyment, or fun as their primary purpose" (Djaouti et al., 2011, p. 25). Some examples are *Zombie Division* (Habgood, 2005), an adventure game for 7/8-year-old children to learn mathematics (Habgood, 2015) or *CosmiClean* (LuGus Studios, 2019), a puzzle game on the topic of recycling.

The third option of game-inspired methodologies for learning is the technique referred to as gamification. Deterding et al. (2011, p. 13) define the notion as an informal term to describe "the use of design elements characteristic for games in non-game contexts" to improve user experience and user engagement in the mentioned contexts. Most importantly within the framework of this investigation is that, instead of making use of games as a holistic artifact, gamification employs some elements, that is parts of games, for the benefit of other non-game-related contexts. The gamification technique is exemplified in various studies, such as a gamified course to improve the engagement of web-based education (Domínguez et al., 2013) or integrating a game achievement system into learning tools (Denny, 2013; Fitz-Walter et al., 2011).

This present study draws upon theories and research that fall into a different category than the mentioned practices to use games for the benefit of learning. That is, here a strategy is investigated during which learners make games for learning. Particularly, the present study situates students in the role of game designers to learn chemical engineering during the game design process. Making games involves a series of learning opportunities beyond software development or computational material in line with the reconceptualization of new literacies, such as computers (diSessa, 2001), that can be used as educational tools and socio-cultural contexts in which young people live and spend their spare time (Gee, 2018).

Despite the recent academic interest in learners making games for learning (Gee and Tran, 2015; Kafai and Burke, 2015;), this body of research has focused predominantly on K-12 students and requires further approaches principally in higher education (Jeffrey Earp, 2015; Hung et al., 2020; Dinç, 2022, p. 2). Particularly in the chemical engineering discipline, making games is a rare learning practice, and game-based learning beyond playing simulation games, e.g. *Sigma Pipe* (James Rodney, 2016), has not been much explored (Udeozor et al., 2022). In fact, Udeozor et al. (2022) observed in their systematic review that software engineering was the engineering discipline in which games for learning were mostly used, which evidences the overall lack of attention to investigate how games can benefit learning other subjects in engineering.

This investigation proposes a novel learning approach to reinforce chemical engineering education. The specific learning strategy sets out from learners creating a game, which draws on the hypothesis that this type of approach empowers learners, and encourages problem-solving skills and creativity. To educate students able to come up with creative and innovative ideas in their expertise, especially in STEM (Science, Technology, Engineering, and Mathematics) disciplines, new methodologies that encourage learners to solve problems must be considered (Zimmerman, 2007; Priemer et al., 2020, p. 106; Astuti et al., 2021 Bulut et al., 2022, pp. 1-2).

1.2 Research question and aim

To tackle future sustainability and energy issues (Varma and Grossmann, 2014; Ellis et al., 2005, p. 1148-1150), chemical engineering students need activities to reflect upon and apply their creativity in higher education, and, hence, the question *how students in chemical engineering education can benefit from making games* represents the starting point of this investigation. For research purposes, this main question can be broken down into more concrete research questions:

1. what learning approach can facilitate that learners make games for learning,
2. which tools are necessary to facilitate game making as a learning practice for chemical engineering students,
3. how can learning be measured during a game creation activity,
4. how can game making as a learning practice be integrated into curriculum-based education, and

5. what are the implications of conducting a game creation event in an undergraduate process design course of chemical engineering.

As the questions imply, the aim of this research can be divided into two parts. Firstly, it is focused on the conceptual aspects necessary to conceive and conduct the experimental activity. This conceptual part considers learners, that is chemical engineering students, education practitioners, tools, and educational context, i.e. cultural trends and events. Next, as additional conceptual work, the study analyses the assessment methodology and, consequently, the learning objectives of the activity, which is framed within a process design course of an undergraduate program.

Secondly, a study case in a process design course is conducted and the results are addressed. Specifically, this investigation analyses and discusses the cognitive, motivational, and social outcomes but other observations and implications of the intervention form part of the analysis.

1.3 Contribution

The contributions of the present investigation can be summarised as:

- Custom connection of existing educational theories, cultural trends, and notions that are part of published academic work, e.g. constructionism (Papert, 1980; Papert and Harel, 1991), game jams (Kultima, 2015a), or intrinsic integration in serious games (Habgood et al., 2005a, Jacob Habgood and Ainsworth, 2011), to investigate how making games can benefit learning.

- Original learning approach, named CHEM Jam, to empower and motivate learners with a game creation event in chemical engineering education.

- Custom-made game editor as an educational tool inspired by mainstream jump'n'run or action games, i.e. platformers, and drag-and-drop level editors to create levels during the CHEM Jam event.

- The GaLeJam model, a conceptual framework highlighting the principal steps of a design-based research necessary to integrate game level jams in higher education as a constructionist practice.

- Analysis of cognitive, motivational, social, and other implications resulting from a game level jam intervention in a mandatory course of chemical engineering education.

- Critical discussion and suggestions of future perspectives in line with making game levels and games for learning STEM in higher education.

1.4 Clarification of concepts

Since the meaning of some words can lead to confusion if interpreted differently than intended, it is esteemed necessary to clarify the main concepts referred to in this investigation and how they are ascribed:

Chemical equilibrium

Calculating the equilibrium composition of a chemical reaction is a fundamental part of chemical reaction engineering. For those reactions that are reversible, which means that "reactants form products that undergo the reverse reactions to reform the reactants" that can reach a point "at which the rates of forward and reverse reactions are equal. At this point no further composition change takes place, and the reaction mixture is in chemical equilibrium" (Felder et al., 2017, p. 114).

Collaborative learning

In this investigation, collaborative learning is "a situation in which two or more people learn or attempt to learn something together" (Dillenbourg, 1999, p. 1).

Commercial or mainstream games

Commercial or mainstream games are a type of game that present entertainment, enjoyment, or fun to players as a primary purpose, as opposed to serious or educational games.

Constructivism and constructionism

Constructivism is an educational theory fundamentally based on learners building, or *constructing* as the name implies, their own knowledge (Fosnot and Perry, 1996; Jonassen and Marra, 2011). Some philosophers theorised about constructivism, e.g. Lev Vygotsky, Jerome Bruner, or Howard Gardner, and presented theories or applications with different variations. Among those theories, Jean Piaget's cognitive constructivism and his influence on Seymour Papert's work that initiated constructionism are the most significant studies for this investigation.

Piaget argued that infants acquire knowledge by creating new mental models in their minds that result from experimenting with their surroundings (Piaget, 1954; Piaget and Roberts, 1973). Setting out from that, Seymour Papert introduced a new learning strategy consisting of using computers as educational tools to learn mathematical concepts (Papert, 1980; Ackermann, 2001).

The present investigation affirms that Papert's constructionism extended Piaget's theory because learners create an artifact, in addition to knowledge, which adds a socio-interactive dimension to learning (Papert and Harel, 1991; Papert, 1993; Shaw, 1995).

Engage, motivate, immerse and empower

In the present investigation, it is argued that game design for learning *empowers* learners because a digital artifact is created. Game jams are a type of competitive game consisting of making games that *motivate* participants (1.4). Both empowerment and motivation are used to *engage*/*immerse*[1] learners in the learning outcomes of this investigation.

[1] The terms *engage* and *immerse* are used interchangeably as synonyms in this investigation.

Engineering process design

The job of an engineer is to design or operate a process, which refers to "operations that cause a physical or chemical change in a substance or mixture of substances" (Felder et al., 2017, p. 35). Designing an engineering process involves producing a process flow diagram of the process layout, as well as specifying each process unit involved (e.g. heat exchangers, reactors, etc.), and the conditions at which the units must be operated (Felder et al., 2017, p. 35).

Games

In this study, the terms *games*, *videogames*, or *computer games* are used indistinctly to refer exclusively to digital games, i.e. games in any digital form, unless otherwise mentioned. Bergonse's definition of videogames (2017), which results from analysing relevant previous studies, is how games are understood in this investigation: "A mode of interaction between a player, a machine with an electronic visual display, and possibly other players, that is mediated by a meaningful fictional context, and sustained by an emotional attachment between the player and the outcomes of her actions within this fictional context."

Game jams

Game jams are hackathon-like events to create games in a relatively short period of time, i.e. between two or three days (Kultima, 2015a; Wirman, 2022).

Game level

The present investigation is focused on level design, which differs from game design. A game level refers to the combination of specific gamespace elements that are defined by Totten (2014, p. XXIV) as the outcome of a "thoughtful execution of gameplay into gamespace for players to dwell in". For this study, learners create game levels with the custom-made Game Editor for Learning (3.2).

Generative learning

Wittrock's generative learning theory (1974) proposed a new model of human learning based on the notion of transfer of knowledge or knowledge transfer, which is one of the cognitive effects of conducting the learning approach proposed in this investigation. Knowledge transfer occurs when learners actively apply prior knowledge from one specific context to another context (Wittrock, 1974; Pea, 1987; Perkins and Salomon, 1994).

Hackathons

Hackathons refer to events that involve the creation of products and services, mostly digital (Lodato and DiSalvo, 2016).

Indie games

In the same line as what occurs with independent films or music, there is often a lack of scholarly consensus in defining what is an indie or independent game (Juul, 2020). Since the Indie Game Movement initiated in the 2000s, indie games are generally understood as small versions of games, normally experimental or different from mainstream games in some way, financed alternatively (Lipkin, 2022).

Informal and formal learning

Informal learning within the contextual framework of this dissertation refers to a learning practice or methodology that stems from a non-institutionalised context. Formal learning, on the other hand, is used to refer to learning practices and methodologies comprised in curriculum-based education.

Intrinsic integration

The notion of *intrinsic integration* in this investigation refers to how learning content is integrated within the gameplay of serious games. The notion, coined by Habgood et al. in 2005, is used when the content of an educational game is integrated both visually and interactively with the game. Particularly for this study, new chemistry-related game items are integrated intrinsically into a platform game level if the items do not only reveal information about chemistry through their appearance but also through their behaviour during gameplay.

Intrinsic motivation

The "natural tendency manifest from birth to seek out challenges, novelty and opportunities to learn" (Ryan, 2009, p. 1).

Learner-centred pedagogy

Learner-centred or student-centred pedagogy is a type of active learning typically associated with a constructivist learning approach because knowledge is understood as the outcome of learners' active role during the experience. Instead of knowledge being received by learners from instructors, learners create knowledge based on their own experiences (Prosser et al., 1994; Sin, 2015).

Maker space and making space

A *maker space* is a space used by makers to create. Maker spaces are part of the Maker Movement, an extension of the DIY (Do-It-Yourself) social trend that consists of creatively designing and building material or digital artifacts, usually prototypes, for both playful and useful ends (Martin, 2015).

In this investigation, a *making space* has a broader meaning compared to the notion of *maker space*. *Making spaces* refer to spaces in which any sort of creations are produced, that is, creations typically produced by participants of either maker spaces, game jams, or hackathons.

Paidia and *ludus*

Paidia and *ludus* are two terms used by Caillois (2001, pp. 27-35) to differentiate two types of play. *Paidia* refers to "spontaneous manifestations of the play instinct", whereas *ludus* is "a disciplined, refinement of *paidia*". These concepts are relevant to understanding the argument in this dissertation that game jams originated from the *paidia* of videogame professionals and enthusiasts. Over time, game jams were structured with some rules, e.g. thematic rules, and/or prizes, which is why the events became the game of making a game and, therefore, a type of *ludus*.

Platform games

Jump'n'run, platform games or platformers are a type of action game in which typically the main character or avatar, controlled by the player, must run and jump to avoid obstacles and/or defeat enemies (Minkkinen, 2016; Bycer, 2019; Cossu, 2019).

Platform game level editors

Platform game level editors are a type of game editors that allow creating platform game levels usually by dragging and dropping existing game items in the level (Marone, 2016, p. 9). *PlataGo!* (Super Icon Ltd., 2019) or *Super Mario Maker 2* (Nintendo, 2019) are examples of platform game level editors.

Serious or educational games

Djaouti et al. (2011, p. 25) define serious games as "games that do not have entertainment, enjoyment or fun as their primary purpose".

Simulations

Often in engineering disciplines, the terms *game* and *simulation* can be used indistinctly. However, this is not the case in this study in which the term *simulation* is understood fundamentally in two forms (Harviainen, 2022):

1. Artifacts with which spectators can not interact or very little. Since the interaction offered by simulations has a minor impact on spectators compared to the impact of games on players, simulations do not usually provoke an emotional attachment as games do.

2. A type of commercial game that aims to partially represent reality, like a flight simulator or farm simulator game in which players can live some experiences in the shoes of a pilot or a farmer respectively. This type of simulation triggers an emotional attachment, unlike the previous type.

Skinning

The technique of changing the appearance of game items and assigning existing interactions in the custom-made editor for this investigation is referred to as *skinning* a game item. It is a reference to in-game transactions that allow players to buy a specific appearance, typically for their avatar (Reza et al., 2022). The purchased images are called *skins*. The technique inspired the G.E.L. distinctive feature through which 2D images can be uploaded and used in the levels to ease the process of integrating learning material in the games.

Unit operations

Each chemical process can be broken down into a series of steps called unit operations that refer to the physical and chemical principles occurring during an existing process. For instance, the process to manufacture common salt involves the following unit operations: transportation of solids and liquids, transfer of heat, evaporation, crystallization, drying, and screening (McCabe et al., 1993, pp. 4-5).

1.5 Structure of the dissertation

This book presents a bottom-up structure that sets out from the theoretical background to propose an unconventional learning approach based on making games. The proposed learning approach, the CHEM Jam, is the result of conducting design-based research informed by three main study cases.

In *chapter 2*, the main educational theories and cultural trends are described. These theories and trends have inspired the present investigation to facilitate making games for learning in chemical engineering education. The chapter addresses the pedagogical approach from three different perspectives, representing the main pillars of the theoretical background: the role of learners and instructors, educational tools, and contexts in which learning occurs.

The proposed learning approach of this investigation, called CHEM Jam, is introduced in *chapter 3*[2], which addresses the main question of this investigation. Firstly, the

[2]This chapter is a revised version of the article entitled *The CHEM Jam - how to integrate a*

structural aspects of the CHEM Jam are explained, including the specifications of the custom-made Game Editor for Learning (G.E.L.). Secondly, the CHEM Jam's assessment methodology is aligned with the learning objectives of an undergraduate process design course. Finally, research and critique on the CHEM Jam and how chemical engineering can benefit from game creation events are discussed.

Study one is addressed in *chapter 4*[3]. Mainly focused on conceptual work, this study case sets out on the hypothesis that game level editors could be used as an educational tool for this investigation. An online activity was conducted during which participants with a background in either chemistry or chemical engineering created chemistry-related game levels with the mobile application *Level Editor for Platformers* (Felgo, 2016). The findings suggest that platform games present some structural particularities that could be associated with learning material in engineering processes but improvement is required. Particularly, changes are needed in the features of the mobile application, as well as guidance for participants to carry out the activity effectively.

In *chapter 5*[4], a pilot study is discussed, which was conducted with two graduate

game creation event in curriculum-based engineering education published in the *Education for Chemical Engineers* journal in 2022.

[3]This chapter is an extended version of the work-in-progress article entitled *Super Mario Maker 2 as a Tool for Educational Game Design* available in *Proceedings of the 14th European Conference on Game-Based Learning* published in 2020.

[4]This chapter is an extended version of the article published in the *Proceedings of the 15th European Conference on Game-Based Learning* under the title *Towards an Assessment Framework for Learner-Created Game Levels in Chemical Engineering Education* in 2021.

students in chemical engineering. The participants used the first prototype of the Game Editor for Learning, G.E.L., to create a game level related to the unit operations of ammonia production in chemical engineering processes. The editor is a modified version of the *Level Editor for Platformers* that incorporates a feature through which new game items can be skinned. In other words, in addition to the pre-made items offered by the mobile application to create the levels, the G.E.L. allows making new game items with any 2D image, to which an existing interaction is assigned. The findings in the first part of this study are used to validate the applicability of the G.E.L. with the learning material.

The cognitive effects of making game levels are explored during the second part of study two. Since some of the creators' knowledge and understanding is communicated through the resulting level, it is argued that the level must be analysed qualitatively. The analysis results in a tailored assessment methodology to assess the learning content of the levels when organising a CHEM Jam.

Study three, an intervention at Danmarks Tekniske Universitet (DTU), is described and discussed in *chapter 6*. The CHEM Jam was integrated into an undergraduate course in process design. A mixed methodology of quantitative and qualitative techniques is employed to analyse the results of the intervention. Concretely, the study aims to explore the motivational and social effects of the intervention but other effects are eventually discussed.

The discussion in *chapter 7* presents a critique of the outcomes of the investigation on a broader scope than the discussions in the previous chapters. A conceptual framework, the GaLeJam (Game Level Jam) model, is presented to examine the principal steps necessary to organise a game level jam in formal education. The chapter explores what are the implications of a game creation event like the CHEM Jam in curriculum-based education. The last part includes aspects that should be addressed, suggestions, and improvements when it comes to making game levels and games for learning particularly STEM in higher education.

Finally, in *chapter 8*, the most important aspects of the present investigation are outlined.

Chapter 2

STATE OF THE ART

The principle that knowledge is actively constructed by learners is a fundamental part of constructivism, one of the main psychological schools of thought of relevance in education and learning (Aubrey and Riley, 2016, p. 2-4). This study argues that some constructivist and derived theories and practices are closely related to the mentioned principle, and, hence, can facilitate the development of games for learning. In this chapter, previous work that has most influenced the present investigation is described from three relevant angles in a learning environment: the role of learners and instructors, educational tools, and contexts.

2.1 Learner-centred approach

This investigation set outs from Friedrich Froebel's concept of kindergarten. Froebel was a German educator in the 19th century who founded the Kindergarten Movement (Lilley, 1967; Olsen and Zigler, 1989; Herschbach, 1992). The movement introduced a new learning method based on individual exploration that was adopted in several countries as a pre-school education system. Individuals form understanding by exploring their surroundings through contemplation and self-analysis (Best, 2016, pp. 277-278). Based on this concept of how understanding is formed, Froebel proposed the *kindergarten*, translated literally as *garden of children*, implying that infants needed a place to flourish like flowers (Resnick, 2017) in their own.

Even if the kindergarten approach has been and still is widely applied in the early stages of education, this study advocates lifelong kindergarten-style learning for young adults. Methodologies inspired by how infants learn in kindergarten could likewise benefit learners of any age (Resnick, 2017). In fact, unlike other educational theories referred to later in this chapter, e.g. Piaget's cognitive constructivism (Piaget, 1954; Piaget and Roberts, 1973) or Papert's constructionism (Papert, 1993), the Froebelian learning theory is not exclusive of how infants learn, but to the development of humankind (Best, 2016).

Froebel's theory of learning represents an instance of a learner-centred approach. Instead of instruction-based activities, infants in kindergarten are usually given toys, puzzles, or other tools to use freely. Learning is an outcome of how infants explore and experiment with the tools. This sort of learning resulting from exploratory and experimental activities led by learners is defined in the present investigation as a learner-centred approach.

An example of learner-centred activity occurs when infants play with building blocks. The blocks are very versatile elements that can be combined interchangeably. Infants are the ones to decide how to combine the blocks depending on the desired outcome. In the case of building a castle, infants will need to picture the castle in their minds and start building the imagined picture by combining the different shapes and colors of blocks available. During that process, understanding is created. For instance, infants learn that certain shapes do not match together, or that some other shapes can form the castle tower if they are combined.

The Froebelian system entailed an educational reverse because the understanding was presented as a learner's construct in which the instructor was not an essential actor. This idea was reinforced later by Piaget's theory of cognitive development about how the child learns and makes sense of their surrounding. According to Piaget, infants create models by experimenting with their environment and re-use the created models, named schemas, to make sense of new knowledge (Piaget, 1954; Mooney, 2000).

A child that knows about the notion of a horse has created a model of the concept in their mind. That schema represents the child's understanding of what a horse is. Other schemas would represent each one of the basic colors if the infant is familiar with basic colors. These models remain in the child's mind to be re-used and combined with other models. In the case that a white horse is perceived, the same infant would be able to create a new schema by combining the schema of the horse with the schema of the white color. Hence, even if the child did never see a horse in that color before, they are able to create a new schema from previous knowledge and recognise the animal.

The Piagetian idea that understanding builds upon learners' previous knowledge positions learners in a better place than instructors to decide what can best meet learners' needs. That is why, on one hand, learners need a certain degree of agency over their learning experiences to progress adequately. On the other hand, in learner-centred approaches, instructors should play the role of facilitators in charge of creating critical learning environments that challenge learners with relevant problems (Bain, 2004; Mtika and Gates, 2010). Facilitators can also offer support and constructive feedback to learners (Tudor, 1993).

If students were to work in a kitchen, there would be two types of leading roles: cook or chef. Both roles are responsible for the kitchen and the food that is made in it, but they entail different perspectives on making food. While cooks mainly follow a recipe, chefs aim to try new things and combinations to come up with a new recipe. If we were to transfer these situations into an educational context, we could argue, on one hand, that cooks would play the role of learners that learn by listening to instructors. On the other hand, chefs would represent active learners participating in a typically learner-driven experience based on exploration and experimentation. The latter is the type of learner that this investigation is focused on.

Providing a learner-centred setting in which learners can apply knowledge is particularly relevant in the case of STEM (Science, Technology, Engineering, and Mathematics) disciplines. Besides the explanation of concepts and theories, learning in these disciplines must be strengthened with the application of knowledge. That is, learners' understanding is reinforced when it is effectively transferred to a hands-on activity such as, for instance, solving problems (Hung, 2013; Lehrer and Schauble, 2015; Priemer et al., 2020).

However, learner-centred approaches are not flawless methodologies. To mitigate the main flaws, the present investigation has considered major criticisms of learner-centred activities. Among them, Kirschner et al. (2006) argues that learners lacking enough prior knowledge may experience difficulties to attain the learning objectives if instructions are not provided during the learning experience. In addition to that, framing learner-centred activities within an established curriculum is not an easy task if the exploratory and creative nature of such activities is to be maintained (Fayez and Al-zu, 2013). Finally, and related to the previous problem, an assessment methodology to effectively assess the activities as part of institutionalised education is normally not easily achieved.

How the present investigation tackles the limitations of learner-driven pedagogies to provide an effective experience for chemical engineering students is thoroughly explained in chapter 3.

2.2 Tools

From an educational perspective, this study understands a tool as a medium that has an effect on the learning process. Froebel's Gifts and Occupations introduced practices in which toys are used for educational purposes. The Gifts consist of twenty different artifacts to stimulate children's senses, e.g. wooden blocks presented in boxes that fit exactly to the blocks. The Occupations are a series of various activities ranging from using clay to sewing or a construction kit, among others (Bruce, 2015). The most relevant contribution of this study is the Gift that introduced structural-design toys, similar to the Tinkertoys (Provenzo, 2009, p. 88), on the grounds that understanding occurs by making with educational tools.

Learning as a design process with a technological tool is a methodology that has inspired this study. When designing, learners can use technology as a tool to create a digital product that can be shared to enhance the learning experience. On that ground, this section discusses how computers and digital games can be used as media and what are the implications of using these tools for learning.

2.2.1 Computers as educational tools

Among the educational theories and pedagogies that could motivate the present study's theoretical background, constructionism, introduced by the work of Seymour Papert in the 1980s (Papert and Harel, 1991), represents a primary inspiration. How the present investigation tackles the limitations of learner-driven pedagogies to provide an effective experience for chemical engineering students is thoroughly explained

Piaget presented infants as builders of their knowledge in a purely cognitive manner. In constructionist practices, learners build not only knowledge but also an artifact. Research suggests that learners are more likely to become intellectually engaged when building an external artifact that can be shared (Kafai and Resnick, 1996, p. 4; Plass et al., 2015; Afari and Khine, 2017; Fino, 2017).

For Papert, learning initiates in the same line as Piaget's theory, i.e. cognitively, but the process is subsequently improved by interacting with peers. Cognitive constructivism, particularly the idea of isolated, individual learning, becomes a social construct because learners create artifacts collaboratively (Shaw, 1995). Creators usually feel the need to share what they have created, interact with it and receive feedback from others about their work. These interactive activities, absent in Piaget's theory, enhance the whole learning experience.

With his publication *Mindstorms: Children, Computers and Powerful Ideas* (1980), Papert led an initiative to use computers with children for learning. In the specific environment, called *LOGO*, children use a programming language to make a turtle move around the computer screen and draw on the screen. For example, when the command REPEAT is used followed by a number and instructions between square brackets, the turtle interprets that the instructions must be performed as many times as the number indicates. From left to right, figure 1 shows a square, a spiked circle, and a circle created in the *LOGO* environment with the command REPEAT.

Papert compares computers to kitchens in his book *The Children's Machine: Rethinking the school in the age of the computer* (1993). Both are comprised of tools through which technological artifacts and food, respectively, can be made. Children feel empowered when using *LOGO* in a similar way that chefs do when using innovative cooking techniques, ingredients, or combinations. Both children and chefs are trying to innovate by expressing

Fig. 1: Three examples of the command REPEAT in *LOGO* programming language (Papert, 1980, p. 176)

themselves with unconventional ways of expression.

An interesting aspect of the *LOGO* environment for this investigation is that programming is used as an expressive medium to study mathematical figures and principles rather than programming being just a skill to be learned in itself. This is related to diSessa's infrastructural perspective on literacy (diSessa, 2001, p. 2). DiSessa defines computers as a new literacy and shares his views on literacy as infrastructural and essential in education because it is not just the result of education, but a "driving force within it". Reading and writing are not only relevant for an English class but also needed to learn other subjects.

Similarly, creating mathematical figures with the *LOGO* environment implies a correct use of *LOGO* programming language to make the turtle move and draw. In that case, Papert presented programming as an infrastructural literacy of education because learning programming was a result of using *LOGO*, as well as the medium to learn mathematics.

2.2.2 Games as designable artifacts

This study argues that the tasks with which players are usually involved when playing games are generally similar to the tasks proposed in conventional learner-centred approaches. Players are not only consuming games but also actively acting as agents of how the game develops (Apperley, 2010). In other words, players may have to choose how they want to play as some games are not linear and can be played differently. Examples of games that offer an extended choice or freedom of play are open-ended or sandbox games like *The Elder Scrolls V: Skyrim* (Bethesda Game Studios, 2011) or *Grand Theft Auto V* (Rockstar Games, 2013). When playing this type of games, players construct their own player experiences to the same extent that learners create knowledge in a constructivist setting, which is why games can be learning experiences per se.

When it comes to games and learning, a core argument of this investigation is that designing games is a valuable learning process. Just as players can practice similar skills as learners do in a constructivist-based activity, the game design process is comparable to constructionist activities in which the created game would be the resulting artifact. This argument is associated with the previous reasoning that constructionist practices enhance constructivist theories because learners not only create knowledge but also use a tool to create an artifact. We have a desire to share our creations that entails interactive activities, e.g. among peers or with instructors, in form of questions, feedback, or comments. Those interactions have an effect on the learning process because oblige creators to review or reason around their creations.

By taking on the role of game designers, learning occurs as a side effect of confronting the challenges arising from the creation process. Designing a digital artifact entails supervising, taking decisions, and seeking feedback about the project. When conducting these tasks, designers have to practice problem-solving and collaborative skills. In sum, the game design process is a learning experience that benefits from constructivist aspects such as exploration and experimentation, in addition to the social factors of maker spaces, which is addressed in 2.3.1.

Particularly when designers are asked to create an educational game, the learning activity can be structured around a specific learning material. However, designing games that meet specific learning outcomes effectively when players play the game is not an easy task. In fact, the effectiveness of educational games is a contested topic in the spotlight of numerous studies, including empirical fieldwork and scholarly discussions (O'Neil et al., 2005; Blunt, 2007; Abdul Jabbar and Felicia, 2015; Boyle et al., 2016; De Freitas, 2018).

Among the most popular challenges of designing effective educational games are aligning an engaging game experience with specific learning content, assessing learning to inform effectiveness, or provoking a substantial appeal comparable to the success of some commercial games. The present study intends to use such design challenges as opportunities for learning by focusing on game design processes. Game design for learning has attracted academic attention mostly for the last decade (Earp et al., 2013; Kafai and Burke, 2015; Hava and Cakir, 2018; Weitze, 2021).

Within an educational framework, the technique of making games or playing games in which players can build elements, like homes in *The Sims* series (Electronic Arts, 2000) (Wirman, 2014) or customise parts of the game experience such as the avatar, the character controlled by the player, in *Little Big Planet* (Media Molecule, 2008) (Westecott, 2011), may have the advantage of counting on learners for the actual design of the game, which, in parallel, is part of the own learning experience.

There are different ways to approach game design, from which three are differentiated for this study: programming, modding, and editing tools (Marone, 2016). For programming games, game developers can employ game engines, e.g. *Unity* or *Unreal Engine*, which are a type of software that offer sophisticated features and resources to develop games (Toftedahl and Engström, 2019, pp. 7-8).

Programming

Game engines normally comprise a UI (User Interface) through which the different elements necessary to compose a game, e.g. scripts in a programming language, artwork images, or files for animations, can be grouped together to offer a conceptual visualisation and ease some of the most complex tasks in game development. However, even if game engines can offer extended possibilities technology-wise, the learning curve to use this technology is quite steep, especially for users who do not possess programming skills.

To tackle difficulties encountered by non-programmers, some artifacts are offering a digital environment based on pre-made blocks that contain ready-to-use scripts to replace the programmed scripts (Melcer and Isbister, 2018, p. 4; Zhang, 2020). The block-based system tends to be quite visual and usually does not require so much technical knowledge as using a game engine.

A block-based initiative is presented with *Scratch* (MIT Media Lab, 2007), a project led by Mitchel Resnick that targets primary and secondary school children (Maloney et al., 2004). The program allows the creation of interactive artifacts through which children can create digital artifacts (fig. 2). The main objective of the activity is that creators draw their attention to experimenting with the pre-made blocks without needing to pay attention to technicalities related to programming.

Fig. 2: Image of *Scratch*'s user interface showing the pre-made blocks on the left and the resulting creation on the top right.

Scratch's users can get inspired by observing the pre-made blocks, which intends to have a similar effect as *LEGO bricks* do when children play with the bricks. From this perspective, block-based programming may function as a digital version of physical building blocks that could be used to create educational games about STEM disciplines. However, the different features and variety of options may be an inconvenience if young adults are to find challenging situations to learn about. In other words, it is assumed that making games with *Scratch* would not be an adequate tool for this investigation, because the experience would be too easy for learners to learn by facing challenges.

Modding

Another technique to design games is called modding. This technique refers to modifying an existing game, which can range from simple edits to total conversions (El-Nasr and Smith, 2006; George et al., 2013; Gee and Tran, 2015; Sotamaa, 2022).

Some mods of commercial games have become quite popular, as in the case of *Minecraft* (Mojang Studios, 2009). In fact, the practice of modding is so widespread among the *Minecraft* community that there are websites strictly dedicated to mods of the game like *Minecraft* Mods or Curse Forge. Nevertheless, modding games require advanced technical knowledge because the modification of the original game is executed through the game's code (Gee and Tran, 2015, p. 267). Since chemical students do not normally own the necessary knowledge, using modding to make games for the present study was discarded.

Editing tools

Editing tools to design games have inspired the custom-made editor developed for this investigation. This type of tools usually presents features of both programming and modding techniques and is accessible to non-technical users. Game editors can facilitate an intuitive design process normally based on a drag-and-drop system through which designers build levels by selecting pre-made game items and positioning them on the screen as wished. A level example of *PlataGo!* (Super Icon Ltd, 2019) is shown in figure 3:

Fig. 3: Image of a game level in *PlataGo!* made by selecting pre-made items on the bottom bar menu of the screen, e.g. the tree in red, and placing the selected item on the screen as the tree marked in dark blue. (*Image courtesy of Steam website*)

PlataGo! is a platform game level editor, which is the same type of editor as the Game Editor for Learning (3.2. Editing tools like *PlataGo!* involve designing platform game levels, which means that the creation process is limited to this type of games. Game levels are gamespaces in which gameplay is executed (Totten, 2014, p. XXIV). In other words, level game designers are mainly building player experiences through the creation of spaces rather than working on interactions of the different game elements (Byrne, 2005; Smith et al., 2008, p. 75).

It is argued that a level editor is a feasible tool for the specific learning approach in this investigation. Approaching game making with an editing tool eases the technical complexities of the process and the main focus of the activity changes to how to integrate the learning material into the game. Specifically, using a level editor for this study allows students learning by trying to integrate their expertise in chemical engineering into the levels without needing programming or other technical skills.

By selecting an editing tool through which game levels can be made intuitively that does not require users to have programming knowledge, the present study can offer a learning experience that can easily be incorporated into any higher education program. That is, game making can be used to reinforce STEM disciplines in higher education. It is hypothesised that using a platform game level editor for creating chemistry-based levels can be a learning experience that fits the challenge required for higher education while producing similar effects than *Scratch* does in primary and secondary education. In other words, platform game level editors may be used as an educational tool to support the five essential steps of Resnick's creative spiral (Resnick, 2017, p. 11) as shown in figure 4.

Fig. 4: Resnick's creative learning spiral (Resnick, 2017, p. 11)

The creative learning spiral, comprising five basic steps, i.e. imagine, create, play, share and reflect, is a type of process favoring the practice of creative skills that outlines the structural aspects of designing games collaboratively. The teams start considering conceptual ideas, which corresponds to the step *imagine* in the spiral. Next, the step *create* refers to the actual creation process. The created artifacts, usually prototypes in the case of digital games, are tested, which corresponds to *play* in fig. 4, and that can involve *sharing* with the community or other team members. The feedback received from testing and sharing the game can be used to improve the prototype, leading to *reflection*, after which the steps in the spiral start over.

In sum, game making with an editing tool that allows making games intuitively is a learning process that leads to creators repeatedly thinking, creating, sharing, and learning from their mistakes or other people's comments which is a similar process that chemistry students would go through when carrying out activities in a chemistry lab.

2.3 Educational context

Among the different hats that educators have to wear during their careers, this investigation draws upon the role of educators as anthropologists (Papert, 1980, p. 181), who are aware of their socio-cultural surroundings and use that knowledge for the benefit of teaching. In institutionalised learning, students usually learn within the culture of higher education institutions, which normally differs from real-life conditions (Brown et al., 1989) and tends to disregard the impact of communication media, social media, or digital games in our lives (Jamaludin and Hung, 2017).

The present study affirms that cultural and social contexts should clash with formal or curriculum-based education to tackle socio-culturally decontextualised learning. Hence, to frame the proposed learning experience within cultural trends, this section describes firstly how makers, members of the Maker Movement, create, socialise, share and learn. Secondly, makers' values and behaviours in creation events are compared to those of jammers, participants of game creation events named game jams.

2.3.1 The Maker Movement

The Maker Movement is an extension of the DIY (Do-It-Yourself) social trend that consists of creatively designing and building material or digital artifacts, usually prototypes, for playful and useful ends (Martin, 2015).

The making culture has drawn the attention of educational institutions (Dýrfjörð et al., 2019; Jornet et al., 2019, p. 92; Schad and Jones, 2020, p. 65) mainly to supplement learning through digital fabrication in schools. However, maker spaces originated in a non-educational context, which means that adapting these practices in educational programs implies significant changes when compared to conventional teaching (Halverson and Sheridan, 2014). To study the impact of the Maker Movement on formal education, it is necessary to describe the core values of the movement (Hatch, 2014), which reach beyond creating an artifact.

The making process is guided by makers, who define and plan the strategy to create the artifact. This means that the process can be transformed into a learner-centred activity when transferred to educational contexts. Makers, as members of the making community, normally learn new techniques and expand their knowledge during the creation process. Besides the creation events, it is usual to participate in seminars, parties, and other types of gatherings for learning and socialising. These activities create a feeling of belonging among the members of the community, as well as empowerment.

Using appropriate tools and being familiarised with them is part of the making experience too. With technological advancements, new kinds of tools have eased the prototyping process. Some of these tools are either computer-controlled manufacturing tools, such as 3D printers, or low-cost microcontrollers, i.e. small, programmable computers on a chip. With a greater choice of prototyping resources than in the past, gatherings to invent and make can be organised more easily in present times, which explains the rise of maker spaces in the last decade (Martin, 2015; Schad and Jones, 2020).

Research suggests that maker-centred learning can attract learners to STEM subjects because it provides an environment that reinforces the understanding learned in class with hands-on knowledge (Kurkovsky, 2012; Ke, 2014; Chu et al., 2017). An example is illustrated by a mission to Mars project (Burton et al., 2018a), through which students actualize mathematical principles in the production of a rocket. Other instances of maker spaces for learning in STEM disciplines are the engineering boot camp *Campamento maker* by Gil and Carmona-mesa (2020) or Kafai et al.'s high school workshops to make e-textiles (2014).

A making space that specifically aims to create games is named *game jam*. Overlaps between game jam events and maker spaces are observed, but they do not completely align. The next section delves deeper into game jams and analyses what are the similarities and differences in comparison to maker spaces.

2.3.2 Game jams

A game jam is a hackathon-like event to create games in a relatively short period of time, i.e. from two to three days (Kultima, 2015a; Wirman, 2022). This kind of activities to create games is increasingly attracting the attention of educational scientists interested in maker-centred learning (Preston et al., 2012; Arnab et al., 2012, p. 168; Murray et al., 2017).

One of the main contributions of this study is proposing a game jam for learning chemical engineering concepts and applications. Normally, game creation activities are organised to learn programming or game-related skills (Jeffrey Earp, 2015; Lai et al., 2021), whereas other types of hackathons, i.e. events involving the creation of products or services mostly digital (Lodato and DiSalvo, 2016), that do not involve making games are more frequently organised in the STEM fields (Grace, 2016, p. 43).

However, game jam events are acknowledged by academics as an alternative to traditional teaching in STEM to offer activities that support learners' curiosity, test problem-solving skills, and encourage interaction with other peers (Falk et al., 2012; Fowler, 2016). All types of hackathons can engage participants cognitively and socially, but game jams are largely focused on supporting a playful approach (Grace, 2016).

Making games to learn STEM-related topics is generally perceived as a fun activity (Meriläinen et al., 2020). Beyond the game making process, game jams are fun because they offer a playful competition. The competition presented is ultimately a type of game consisting of making a game for enjoyment in which eventually a winner is selected. Caillois (2001) would use the term *paidia* to refer to the spontaneity and improvisation of a game of this nature. He argues that the term *paidia* "covers the manifestations of the play instinct" (Caillois, 2001, p. 27-28) such as infants do when playing in the schoolyard or a dog running after a ball. In this study it is argued that what makes game jams playful and perceived as fun is that they were an example of *paidia*, originated from the manifestations of play instincts of game professionals, students, and enthusiasts. Over time, game jams introduced some regulations or constraints, e.g. a winner or theme-based events, which turned game jams into an example of what Caillois names *ludus*, which occurs when *paidia* is refined and subordinated by rules.

Popular game jams events, e.g. the Global Game Jam or the Nordic Game Jam, focus on making games in teams. In fact, gathering multidisciplinary teams was a reason why game jam events originated two decades ago (Lai et al., 2021). Making digital games is a complex process requiring multidisciplinary knowledge, e.g. computer science, design, or digital art. In interdisciplinary game jams, individuals often meet other individuals with complementary backgrounds to form a game development team. Their interest in games is what bonds such diverse teams together.

In maker spaces, motivation is driven principally by social interest. Learning occurs around the idea of working collectively to share new knowledge and learn within the community. However, besides learning, jammers are mainly attracted by the networking possibilities of game jams (Fowler, 2016). On some occasions, game-jam-created prototypes have become a commercial success, which supports the efficacy and significance of these events. Examples of that are *Fortnite* (Epic Games, 2017), which began in an internal game jam at the game company Epic Games, or the indie game *Baba Is You* (MP2 Games, 2017), Nordic Game Jam winner in 2017.

The connection between game jams and the gaming industry is obvious, with some indie game companies and aspiring game developers considering game jam events a feasible entry point to the industry (Meriläinen et al., 2020). In fact, the events usually kick off with talks or workshops conducted by renowned professionals. Pirker et al. (2016) concluded that game jams bridge the divisions between students and professionals when organised in undergraduate or graduate game design and development programs.

As in other hackathon events, jammers aim to create prototypes in limited time-framed events. Restriction of time is a constraint in the competition that introduces some advantages within a design framework such as speeding up conceptualisation, decisions, and prototyping (Olesen, 2020).

Another frequent practice in game jams is announcing a theme, on which the created prototypes must be based, usually right after the initial talk or workshop of the event. This practice originates a significant surprise factor in participants that encourages improvisation during the creation process. Generally, constraints in time or theme foster creativity in game jams (Kultima, 2015b; McDonald and Moffat, 2016). Most importantly, the constraints used in game jams incorporate a new degree of difficulty to the competition that can attract participants who are eager to face new challenges (Earp et al., 2016).

Overall, it is argued that game jams are events that originated in informal environments that should be considered to reinforce learning and benefit formal education. Additionally, game jams, unlike other types of hackathons, have the particularity to introduce a playful experience to attract and motivate learners. Thus, the present study proposes a game creation event inspired by game jams to engage learners playfully, cognitively, and socially with curriculum-based topics in chemical engineering education.

2.4 Conclusion

The present study introduces a learning strategy inspired by educational theories in which learners perform a leading role. It is argued that such a learning approach, which is typically applied in pre-school settings, is a valid methodology for young adults. The approach can benefit higher education in STEM mainly because supports learners' curiosity and tests their problem-solving skills.

In the specific strategy, learning originates as an individual construct from learners, echoing Piaget's cognitive constructivism, which results from exploring and experimenting with the surroundings. Piaget's theory was later extended by Papert's constructionism and his *LOGO* programming language, an initiative for children to learn by using computers as an educational tool.

An argument of the present study builds largely on the idea that constructionist practices enhance constructivist theories because learners not only create knowledge but also an artifact. When we create an artifact, we have the desire to share it and receive feedback from others, which has a positive impact on the learning process.

Players who are playing games, especially games allowing different play styles and outcomes, must make decisions to create their own player experience just as in a learner-centred constructivist environment. Similarly, the game design process, which is the focus of this investigation, is comparable to a constructionist learning setting in which the game is the resulting artifact. Overall, it is argued that making games for learning in STEM disciplines provide learners with all the constructivist attributes together with the social and interactive benefits of maker spaces.

Drawing on cultural trends, the learning experience presented in this investigation is structured as a game jam event. Game jams are hackathon-like events to create games in a relatively short period of time. These events benefit from time restrictions and other constraints to promote creative ideas. Graduate and undergraduate programs in STEM can motivate students by offering a playful, informal competition such as a game jam.

Chapter 3

THE PRESENT LEARNING APPROACH

This study argues that prompting learners to create game 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. Drawing on that argument, this chapter aims to outline the outcome of the present design-based research: a novel learning experience with game making at its core to reinforce chemical engineering education.

This chapter starts analysing the proposed learning experience, named CHEM Jam, from the perspective of learners, educational tool and context in connection to chapter 2. Participants use a custom-made Game Editor for Learning (G.E.L.) 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. After that, the structural elements of the CHEM Jam are described.

The second part of this chapter addresses the CHEM Jam as a practice for chemical engineering educators and facilitators. The CHEM Jam is integrated into the chemical engineering curriculum by aligning the assessment methodology with an undergraduate course on process design. To show the applicability of the methodology, a case study is assessed.

3.1 Students as game producers

To propose a learner-centred pedagogy, this study presents the CHEM Jam, a game jam for chemical engineering students to design game levels collaboratively.

During the CHEM Jam, students are asked to creatively project their expertise in chemical engineering in the levels that are being created. The activity represents a challenge for students to practice the learning outcomes of the course in an unconventional setting. Similar to group projects that aim to practice, for instance, chemical principles or theories, the activity encourages students' collaborative exploration and reflection around the learning content.

Nevertheless, beyond conventional project-based or case-based activities, in the proposed learning model, participants take on the role of game designers. Instead of consuming games, learners acting as game designers perform an empowering producing role (Gee, 2005, p. 6), through which fun, memorable and unique experiences can be created. From their leading, active role, students explore and create their own learning experiences to communicate particularly their expertise in engineering design processes through the levels.

3.2 The G.E.L. as educational tool

The G.E.L., Game Editor for Learning, is a custom-made editor for this investigation through which users can make, test, and play 2D platform game levels. The editor is an enhanced version of the open-sourced *Level Editor for Platformers* (Felgo, 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 run and jump to avoid obstacles and/or defeat enemies (Minkkinen, 2016; Fornós, 2020, p. 804). Platform game level editors allow creating game levels usually by dragging and dropping existing game items on the level (Marone, 2016, p. 9), which means that users do not require programming skills.

The G.E.L. features a drag-and-drop system to create the levels. For their creations, users can choose between using the existing items in table 1 or, unlike other popular drag-and-drop game editors, skinning existing items with a 2D image of their choice. To skin or create new game items, users must select the 2D image that they wish, upload it to the editor and assign one of the item's type in table 1, which define how the item interacts in the gameplay. 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 to chemical engineering processes. This particular feature of the G.E.L. aims to facilitate the integration of the learning material into the game levels through the creation of new game items.

The editor offers nine different pre-made items divided into three categories: terrain, enemies, and power-ups (table 1).

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.

Terrain items are floor tiles that can be used as platforms for the avatar to jump on them. Sharp elements are another type of terrain items in the G.E.L. The avatar should avoid stepping on sharp elements because it will get hurt by losing a life or dying if the avatar does not have any life left.

There are two different types of enemies, both with a negative effect on the gameplay as the sharp elements. However, unlike the terrain items, the enemies move around the game which means that they may approach the avatar unnoticeably. The avatar can kill enemies by jumping and hitting on their heads.

Power-ups have a positive effect on the gameplay because players will receive a certain advantage, depending on the type of power-up, when picking up one. With the star, the avatar will turn into an invincible state, a state under which the avatar will not be hurt by enemies or other hazards. The avatar will see its size double if in touch with the mushroom, which will allow a higher jump than the jump in regular size. The mushroom increases by one the number of the avatar's lives. Finally, the avatar can also collect coins in a game. The total number of accumulated coins is displayed on the coin counter on the top-left side of the screen.

In view that the type of available interactions in the G.E.L. is quite limited, exploring how to integrate the learning content and convey a message within this limitation is part of the challenge and, hence, of the learning experience.

To give an example of how new game items can be created and used in the G.E.L., figure 5 shows a screenshot from a game level created with the G.E.L. that includes four new game items.

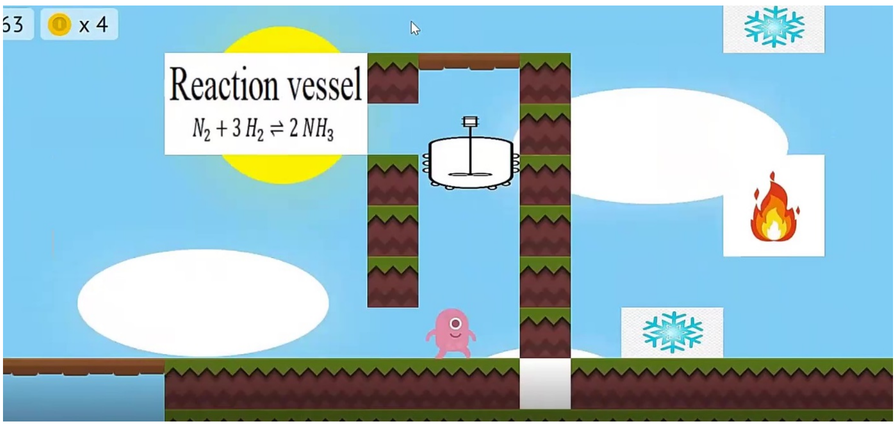


Fig. 5: Screenshot of a game level created with the G.E.L. in a pilot study, addressed

in chapter 5, including new game items, i.e. the reaction vessel and formula sign, the reactor image, fire, and ice elements.

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 positive and negative behaviour, respectively, to indicate that the reaction will occur faster at a higher temperature.

3.3 Game jams in formal education

By providing a drag-and-drop tool to make game levels, the CHEM Jam ensures that students' attention during learning is not distracted by programming or other technical skills related to game development. This approach aims to direct students' attention, particularly to relevant content in the chemical engineering curriculum.

Attracted by the empowering effects of making games, students participate in an activity inspired by game jams that engages them cognitively, socially, and playfully. During the CHEM Jam, learning occurs cognitively throughout the design process by reflection and experimentation (see 3.4). The social engagement of the activity is reflected in the collaborative aspects, i.e. peer-to-peer interaction and additional feedback during creation or on the already created level. The CHEM Jam is overall an informal competition that can motivate participants playfully due to the playful approach of game jams. In addition to the before-mentioned benefits, when used in formal education, game jams can help to approach students about the game industry (Hrehovcsik et al., 2016; Pirker et al.). Similarly, when integrated into curriculum-based engineering education, the CHEM Jam can bridge chemical engineering students to game design and serious games.

However, using student-centred activities in curricular programs is not an easy task. Participants need to receive a balanced type of guidance that is appropriate for each occasion. On one hand, the activity needs to be appropriately framed within the intended learning outcomes. On the other hand, it should be considered that learning occurs by students driving their own experiences, which means that student-centred activities benefit mainly from non-instructional learning. The dichotomy between framing learning within curricular activities and benefiting from non-guided experiences is mitigated in this investigation through the structural aspects of the CHEM Jam. The activity is structured in three stages, introductory stage, stage one, and stage two, that facilitate the minimal guidance needed, while maintaining effectiveness, for learner-centred activities in curricular contexts.

3.4 Structural aspects

The CHEM Jam is structured to re-create Resnick's creative learning spiral (figure 4 in chapter 2) and benefit from a creative, unconventional way of learning. Students start by imagining how the game levels can be used as a medium to communicate the learning content. Next, students create the levels, which are played and shared to test if the message is conveyed as they wish. Part of learning occurs by testing and commenting on the level, which involves a reflection process related to the learning material integrated into the level.

The different cognitive engagements that learners adopt during the CHEM Jam are inspired in this study by Michelene T. H. Chi's ICAP model (Chi, 2009, pp. 719-720). The model is structured in four modes of engagement, namely passive, active, constructive, and interactive (fig. 6).

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

Each mode of engagement corresponds to different types of learner's behaviours and learning processes. This investigation coincides with Chi and Wylie that the passive mode involves a receiving behaviour that can happen, for instance, when learners are listening to a lecture or watching a video.

However, in this study, the remaining three modes, i.e. active, constructive and interactive, are understood differently than in figure 6. The active mode is triggered by any action conducted by learners. Reading a text, for instance, is regarded in this study as an example of the active mode of engagement, unlike in the ICAP framework in which such an action is described in the passive mode.

Here, constructive and interactive modes are understood as subcategories of the active mode because the three modes involve actions conducted by learners. The main differences are that learners with constructive engagement will generate an artifact as a result of their learning process, whereas the interactive mode would result from any form of interaction. From this perspective, the example of explaining concepts in a video would be related to an interactive mode of engagement instead of a constructive mode as described in figure 7.

Throughout the three stages in which the CHEM Jam is structured, different types of learners' engagements are triggered (fig. 7), combining the four modes of engagement previously explained:

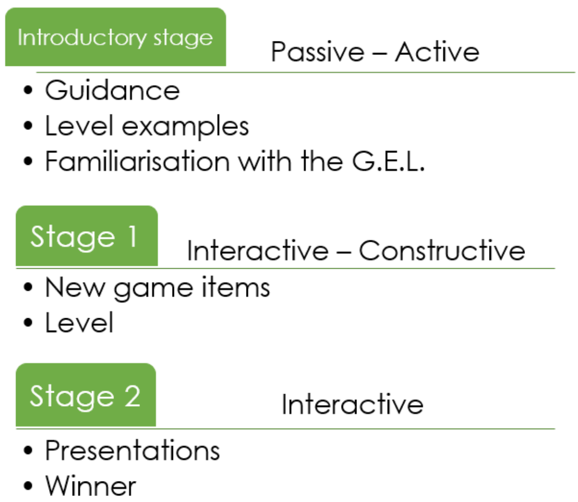


Fig. 7: The three stages of the CHEM Jam in green, the type of engagement on the right and the tasks conducted in each stage in bullet points.

3.4.1 Introductory stage

The introductory stage of the CHEM Jam presents the structure and assessment methodology of the activity to the participants (*Guidance* in fig. 7). The assessment methodology, which is thoroughly described in subsection 3.5.1, evaluates mainly the learning content of the game levels to frame the CHEM Jam in the process design course.

Certain level examples are shown for inspiration during the introductory stage, even though an experimental and innovative approach during the level creation cycle must be highly encouraged. To encourage creative levels, a category has been included in the scoring system of the levels, through which the degree of creativity and originality of a level will be assessed (see 3.5.1). For instance, it will be considered a lack of creativity that teams use the same images in the level examples or other facilitated documentation, which should be informed in the assessment methodology accordingly.

To end this CHEM Jam's stage, participants proceed to download the G.E.L. and get familiarised with the editor by using and testing the different features. Additional documentation, e.g. a tutorial for first-time users, is facilitated.

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

3.4.2 Stage one

In stage one, participants work collaboratively to create levels with the G.E.L. Participants 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 should be used as an interactive channel through which students can communicate what they are learning in class. Using images and representations of chemical/physical phenomena or other information related to process design, especially those aspects that are not possible to reproduce in diagrams of engineering processes or simulator programs, should be assessed positively in the creativity criterion of the assessment and overall in the learning experience.

During the level creation process, participants need to adopt a constructive behaviour. This is so because a digital game level is generated as a result of the creation process. Additionally, the interactive behaviour is triggered because the levels are created collaboratively, which requires interaction.

3.4.3 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 the 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. 14). Therefore, these elements should be maintained within the limitations of formal education.

3.4.4 Recommendations

The CHEM Jam's creation process (stage one) should last at least 6-8 hours and should preferably be facilitated in an informal space, e.g. a lounge area with an internet connection and a big screen, where food, snacks, and drinks are offered. The space is especially relevant to try to create a feeling of belonging to a community, similar to communities created by maker spaces, in which participants can count on their peers to learn and get inspired.

Game jams are normally held for two or three days during a weekend, which, should be maintained to preserve the benefits of time restriction in these events. However, to integrate the CHEM Jam into a process design course, it is necessary 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 at 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.

3.5 Curricular education

This investigation advocates for activities inspired by constructionist approaches that attempt to achieve the most positive results learning-wise within the least of instruction (Fino, 2017). Nevertheless, that is not an easy task in curriculum-based education since learning outcomes must meet pre-established curricula (Pozzi et al., 2020). To offer a suitable activity for chemical engineering education, this research proposes to align the pre-established content of a mandatory course in chemical engineering with the CHEM Jam's assessment methodology.

3.5.1 Aligning assessment with learning outcomes

Learner-centered activities can be effectively integrated into 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. 8) of the undergraduate Process Design course at Danmarks Tekniske Universitet (DTU).

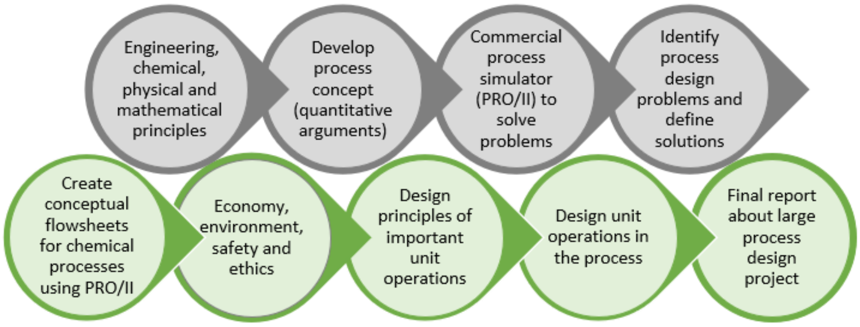


Fig. 8: Intended learning outcomes of the process design course at DTU. The green-marked outcomes are directly connected with the CHEM Jam whereas the grey ones are connected indirectly.

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 intended 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. 8). The green-marked ILOs are the ones directly represented in the game levels and on which the assessment framework (fig. 9) is based.

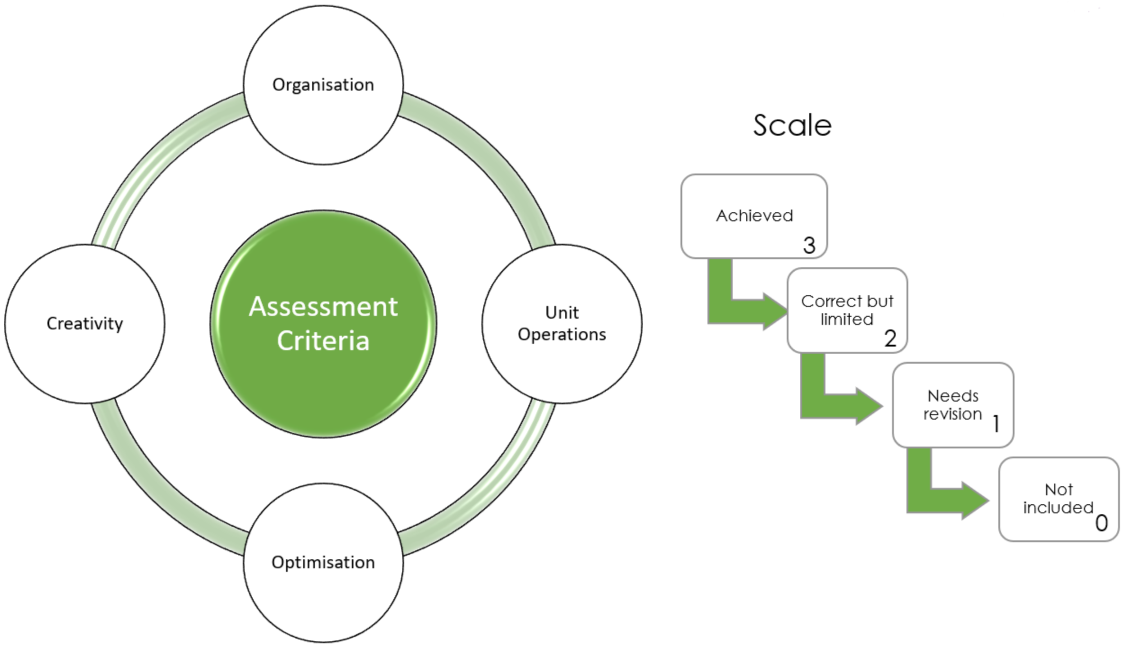


Fig. 9: The CHEM Jam's assessment framework includes assessment criteria (left) and a grading scale (right).

Through the assessment framework, which is an improved version of the assessment methodology resulting from conducting the study addressed in chapter 5, the learning content covered by the game levels can receive 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 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 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 for 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 it difficult to represent ethical aspects, in which case they should mention them 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.

3.5.2 Case study

In Appendix C, some gameplay videos of levels representing cumene production are included. These levels were created during an intervention conducted in Autumn 2021, in a collaborative event between IT University of Copenhagen and DTU. Details of the intervention can be found in chapter 6.

In this section, the gameplay video of group 9, corresponding to the level that won the CHEM Jam at DTU, is assessed with the CHEM Jam's assessment framework to demonstrate the applicability of the framework (fig. 10).

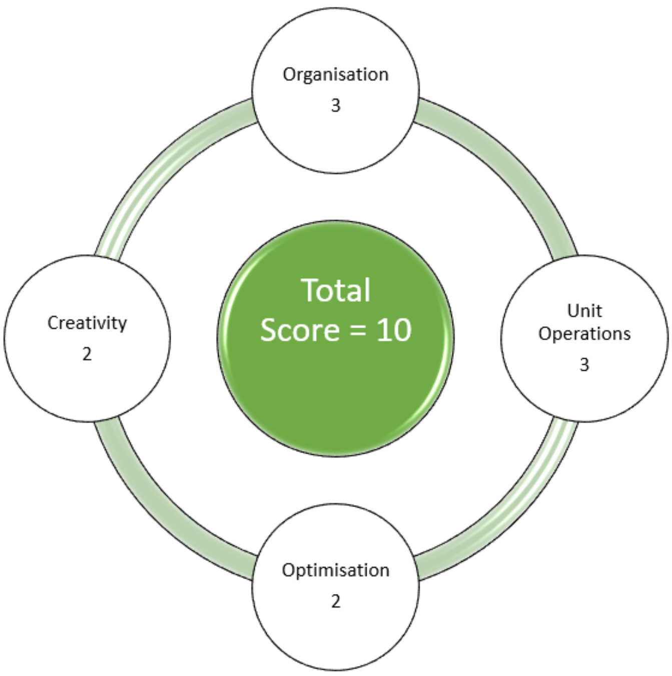


Fig. 10: The assessment of a level example.

The total score of 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 figure 11 have been represented in the level.

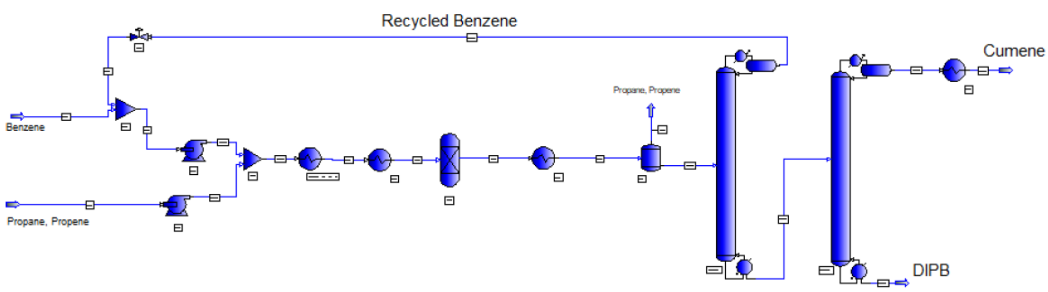


Fig. 11: The process flow diagram generated with the simulator PRO/II.

The PFD for cumene production in the figure 11 consists of the following unit operations: stream mixers, compressors, heat exchangers, reactors, distillation columns, and condensers.

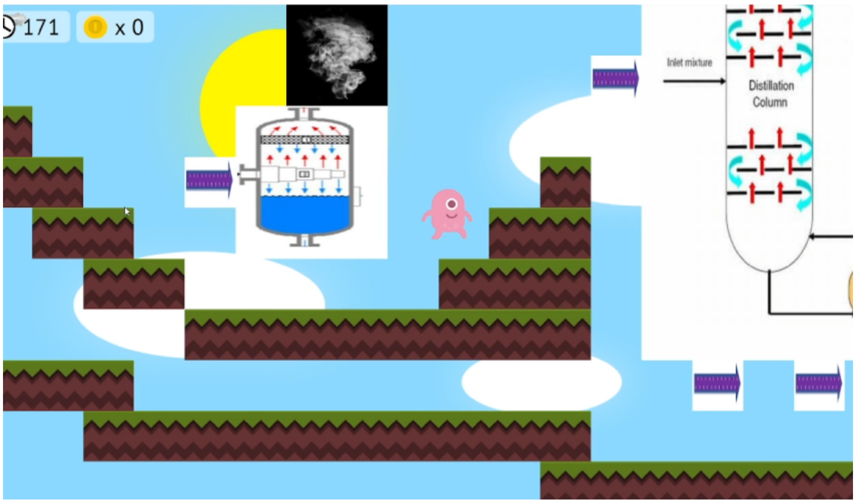


Fig. 12: Screenshot of part of the level showing two core unit operations: a flash tank on the left side of the screen and part of a distillation column on the right.

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 (fig. 13 and 14). 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.

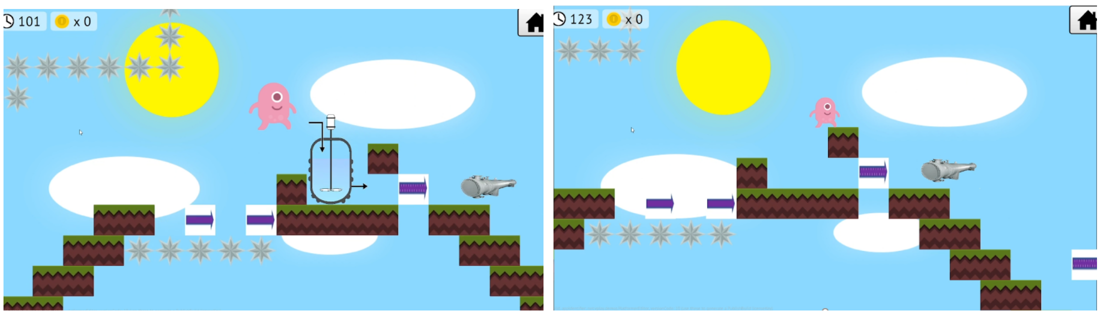


Fig. 13 and 14: Screenshots of the level with the oversized avatar before hitting the reactor (left) and back to normal size after being hit by the reactor (right).

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. 15). It was considered that the levels would have been more creative if the original pictures had been used.

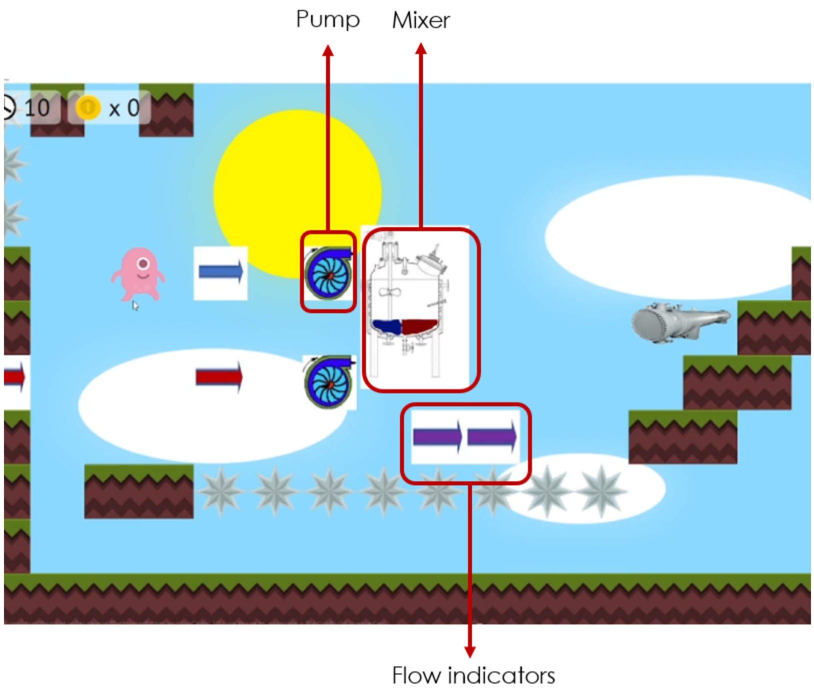


Fig. 15: The images used for the pumps, the mixer, and the flow indicators in this picture were the same as the images used in the inspirational level.

3.6 Impressions

The Associate Professor and course manager of the process design course at DTU to 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 in 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.

3.7 Discussion

The G.E.L. is not intended to replace the functionality of process simulators in engineering education, 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.

Activities that promote learning transfer, i.e. the improvement of learning 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 at 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 is integrated into a platform game level for the benefit of learning.

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, specific chemical and physical phenomena. Those changes would allow representing high-fidelity unit operations 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 on the 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 to 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.

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 but some interaction will remain, particularly in the stage two, through level presentations and feedback given by facilitators.

In recent years, new online platforms, e.g. *Roblox* (Roblox Corporation, 2006), *CREY* (CREY Games Aps, 2016) or *Core* (Manticore Games, 2021) 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 extent 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 time-frame. 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.

Chapter 4

STUDY ONE: CONCEPTUAL WORK

The proposed learning approach in this investigation described in the previous chapter is the outcome of conducting three empirical studies. This chapter addresses the present investigation's conceptual work, mainly focused on exploring and developing the custom-made editor. Through an activity inspired by the participatory game design technique, this case study explores if platform game mechanics can be aligned with chemical concepts and related content.

Six participants with a background in chemistry or chemical engineering used an off-the-shelf mobile application, *Level Editor for Platformers* (Felgo, 2016), to represent a chemical reaction and citric acid production respectively. The results informed the next steps necessary to consider the specific features of the educational tool and pedagogical approach in this investigation.

4.1 Aim

Setting out from the hypothesis that platform game editors can facilitate game making as a learning practice for chemical engineering students, this chapter aims to explore the possible combinations of the learning material in this investigation with the off-the-shelf mobile application *Level Editor for Platformers* (*LEP*) (Felgo, 2016).

The application *LEP* is an editor through which platform game levels can be made. Particularly, the study analyses to what extent the editor allows the creation of levels with chemical concepts or other content related to the chemical engineering curriculum in view of considering if new features would be necessary to offer an effective learning experience for this investigation.

4.2 Background

Game creation is a process that can reinforce learning methodologies in STEM because trying to make educational games about a specific subject offers a hands-on setting in which creators must reflect upon the subject in question. For instance, to develop a game such as *Portal* (Valve Corporation, 2007), a puzzle game as per Apperley's taxonomy of game genres (2006), based on physics principles (Adams et al., 2016), developers need, among other knowledge, good command and understanding of physics.

However, game development is a complex process that involves technical skills, particularly in programming and game design, and so can easily become a challenge for learners who do not have a background in computer science, game design, or game development. To introduce programming knowledge to beginners, block-based or visual programming environments emerged in compulsory education, targeting mainly infants and pupils, i.e. primary and secondary schools (Duncan et al., 2014; Falkner et al., 2014; Weintrop and Wilensky, 2015; Zhang, 2020).

Visual programming environments may be applicable to higher education but here it is argued that an off-the-shelf game level editor supporting a constrained variety of creations is more suitable for the present investigation than visual programming. The tool should present interactive limitations intentionally to challenge creators to convey their expertise within the available interactions. That requires more effort than other, more flexible programs, and can facilitate the right experience to challenge chemical engineering students.

Game level editors constrain digital creations to levels of a particular type of game (Cowan and Kapralos, 2011, pp. 52-53; Salin and Morrar, 2022). Particularly drag-and-drop game level editors with pre-existing items to create the levels, e.g. *PlataGo!* (Super Icon Ltd., 2019) or *Super Mario Maker 2* (Nintendo, 2019), served as an inspiration to select the application *Level Editor for Platformers* (Felgo, 2006) (*LEP*) for this case study.

Unlike programming or modding techniques, drag-and-drop editors are intuitive tools for non-game designers, which may help students direct their attention primarily on how their expertise, chemical engineering, in this case, can be represented in a game level.

Due to time-restricted curricular programs, employing modding techniques, which can focus on a specific type of game as level editors do, is not recommended. Modding, like programming, would normally require a steep learning curve that can easily divert students' efforts towards learning outcomes that do not form part of the chemical engineering curriculum.

4.2.1 Platform games

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 reach the end of the game alive by running and jumping to avoid obstacles and/or defeat enemies (Smith et al., 2008; Minkkinen, 2016; Bycer, 2019; Melcer and Cuerdo, 2020, p. 267). Platformers are generally fast-paced games with jumping as core gameplay, often on platforms, in which rhythm is key (Compton and Mateas, 2006, p. 109; Smith et al., 2008). For example, knocking down a moving enemy is often only effective if the avatar jumps at the right moment to land squarely on the enemy's head without being hit.

Among the different varieties of platform games, this case study investigates side-scrolling platformers, which means that the avatar progresses in the game by going towards the right side of the screen (Cossu, 2019, pp. 297-298).

Platform game level editors

Super Mario Maker 2 (*SMM2*) (Nintendo, 2019) is a commercial platform game level editor (Mccarthy, 2019) published after the overwhelming success of its predecessor *Super Mario Maker* (*SMM*) (Nintendo, 2015) (Newman, 2016; Lefebvre, 2017). Users of both games had created over seven million stages[1] by 2019 (Johnson, 2019). Initially motivated by its popular appeal (Park et al., 2016; Johnson, 2019), platform editors that allow the creation of platform game levels became the focus of this investigation.

In *SMM2*, users have a large number of different game items to choose from for their creations. In creation mode, users select the items they wish to use and drag the item onto the level that is under construction. Once the item is on the level, it is possible to change to testing mode and see how the selected item interacts in the game space. This action can be repeated for any game item at the users' convenience.

The game items[2] available in *SMM2* are divided into four categories shown in table 2.

GAME ITEMS - CATEGORIES				
EXAMPLES	TERRAIN	ITEMS	ENEMIES	GIZMOS
				
				
				
				

Table 2: Game items categories in *SMM2*.

The *terrain* category, e.g. walls, platforms, or bridges, is used to model the game

[1]The game levels created in *SMM* and *SMM2* are referred to as *stages* or *courses* by the Nintendo franchise (*SMM2* Wiki).

[2]Game items in *SMM2* are called *course parts*.

space around which the avatar can move. This type of items are usually static and not assigned any special interaction in the game.

Items is a category that typically provides the player with some sort of advantage while playing, such as 1-up mushrooms that provide the avatar with an extra life if it is picked up. Challenges and monsters to defeat, each one with its special characteristics, are available in the category *enemies*. Finally, users can find other elements that offer a wide array of interactions and do not fall into the previous categories with *gizmos*.

4.3 Chemistry-related game levels

The number of existing items to create levels in the editor *SMM2* and its variety is very extensive, and some items can easily be associated with chemistry, physics, or chemical engineering, e.g. pipes, lava, or drops. The items that appear on a level can function as a representation of industrial equipment, or part of it, physical phenomena, and other relevant elements linked to chemical engineering education, such as phenomena occurring during a chemical reaction, which may facilitate the creation of chemistry-related platform game levels as shown in figure 16.

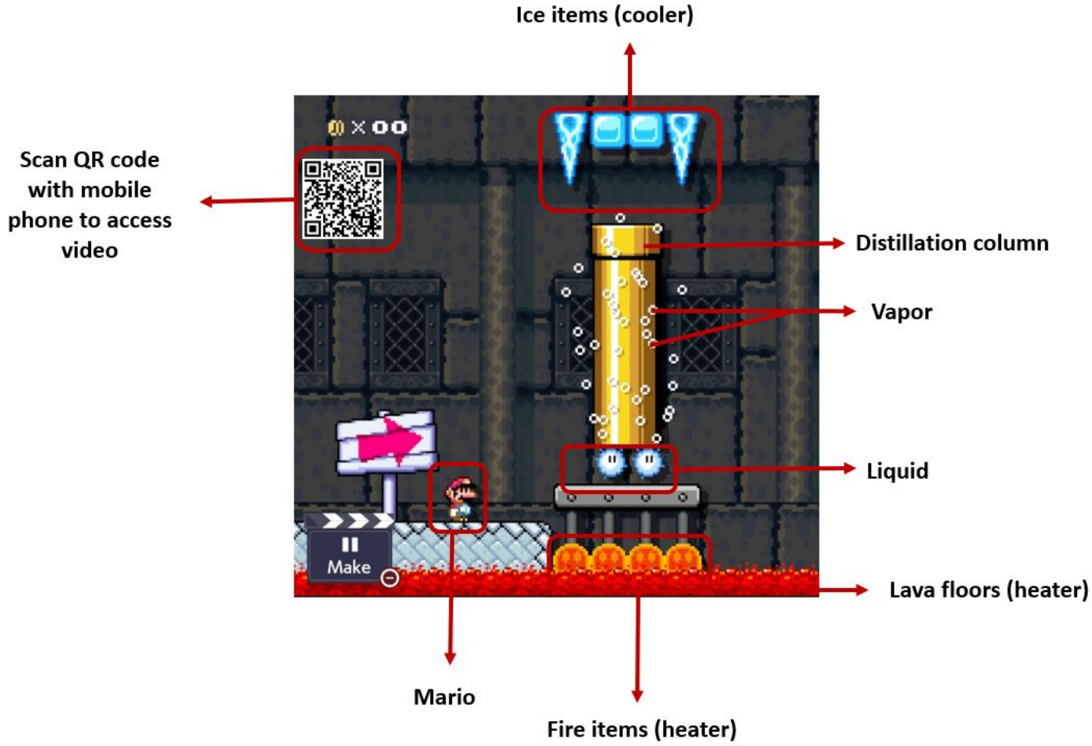


Fig. 16: Improvised representation of a distillation column in a *Super Mario Maker 2* game level.

Figure 16 is part of a game level created in *SMM2* that represents an improvised distillation column. The ice items on the top stand in for the column's cooler, fire items on the bottom, as well as lava floors stand in for the column's heater, and two drops are moving around to represent the solution contained by the column which is going through an evaporation phase.

How the different game items are placed on the level defines the gameplay and the obstacles that Mario, controlled by the player, must get pass in each level. The main objective is that Mario reaches the end of each level without dying too often since the number of lives is limited. In the part of the level shown in figure 16, for instance, Mario must keep clear of the stalactite-shaped artifacts because they are deadly and fall to the floor after a lapse of time. Mario needs to jump on the top of the column, with the help of the jump booster in the vapor, at the right moment to avoid collision with the falling iced stalactite.

Level Editor for Platformers

Despite the evidence that *SMM2* can be employed to make chemistry-related levels, the connection between the editor and the content may be too obvious for undergraduate students and, consequently, the activity may not be effective for the purpose of this investigation. To offer an adequate challenging activity, the (*LEP*), with a much narrower assortment of pre-made items than *SMM2*, is selected to conduct the present study case.

Using the *LEP* for this study is an advantage because the application is open-source. This means that the source code can be modified if this study's results reveal that some adjustments are necessary to use the application as an educational tool for the present investigation. In addition to that, the selected editor is a free mobile application, so the editor is more accessible than console-exclusive games, such as *SMM2*, and can be easily used in curriculum-based education.

The pre-made items offered by the *LEP* are limited to nine items, divided into the categories of terrain, enemies, and power-ups, which have been explained in section 3.2 in the previous chapter. In the creation mode screen of the *LEP* (fig. 17), users can select a pre-made item from the left-side menu, drag the item to the level, and drop the selected item on the wished spot on the level.

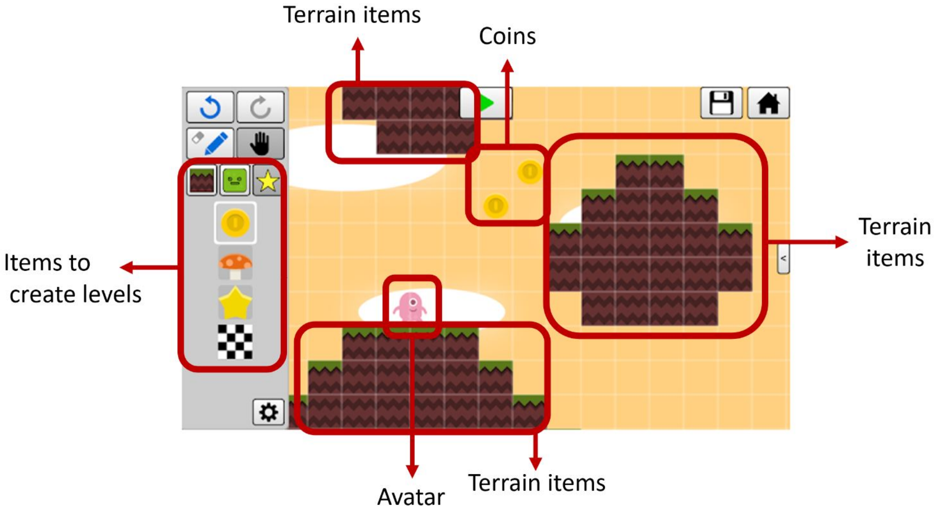


Fig. 17: Creation screen with a level example in *Level Editor for Platformers* (Felgo, 2016).

With the top commands of the menu, there is the possibility to undo the previous action, delete items in the level, or touch the level and move around without selecting or drawing any item.

4.4 Procedures

In November 2020, six colleagues of the CHARMING European Training Network with a background in chemistry or chemical engineering participated in a study conducted online to gain insight on the *LEP* as a tool from a chemical engineering perspective. The study was initially planned with undergraduate students who were not related to the project. However, after several unsuccessful attempts to reach the students online, six colleagues subsequently participated in the study[3].

An email was sent to participants, which included the activity's estimated completion time and submission deadline, how to download and use the editor on mobile phones, and the instructions to complete the activity.

The instructions were divided into two questions. The first question was addressed to chemical engineers and asked them to explain the industrial production of citric acid with a *LEP*'s game level. The second question, addressed to chemists, asked to reproduce the equilibrium formula in figure 18 with the same editor.

$$2H_2 + O_2 \rightleftharpoons 2H_2O$$
$$K = \frac{[H_2O]^2}{[H_2]^2 \times [O_2]}$$

Fig. 18: The equilibrium formula on which some participants were asked to base their game levels for this conceptual study with the *Level Editor for Platformers*.

Figure 18 consists firstly of the chemical equation molecules of hydrogen ($2H_2$) and oxygen (O_2) to produce water ($2H_2O$) in equilibrium. Secondly, the equation to calculate the equilibrium constant is shown, which divides the products ($[H_2O]^2$) by the reactants of the chemical reaction ($[H_2]^2 \cdot [O_2]$).

Participants were advised that, due to the exploratory nature of the activity and the editor's interactive limitations, the experience demanded a high degree of imagination and out-of-the-box thinking. They were suggested to use pre-made items as industrial

[3] The activity was carried out online to comply with the restrictions and limitations in place by the Danish authorities due to the COVID pandemic in 2020.

equipment and chemical concepts or part of them, even if the items had completely different appearances. An example included in the instructions showed a pre-made floor item in the editor that could be used to represent a flash tank, industrial equipment that can be used in engineering processes (fig. 19a and 19b).

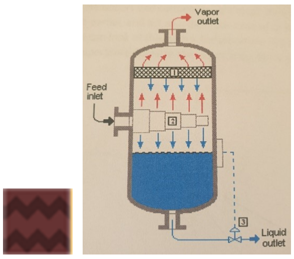


Fig. 19a and 19b: An example was given to use a pre-made floor item on the *Level Editor for Platformers* (left) and to represent a flash tank in their creations (right).

After creating the levels, participants are asked to provide screenshots of their creation together with an explanation about what they intended to represent and their impressions of the activity.

4.5 Methodology

This study case is structured as a hands-on experience based on participatory design, a technique through which designers count on final users to design artifacts cooperatively (Bødker et al., 1988). Previous studies have used the technique to gain insights for developing serious games (Lukosch et al., 2012; Khaled et al., 2014; Ball et al., 2020;), which indicates that this method should also bring valuable insights for the present case study.

From the different stages in participatory design, this study is comparable to a prototyping stage (Spinuzzi, 2005, p. 167). The main difference is that here participants are not aware of how and to what extent their participation will affect the actual design of the editor or its additional features. Participants use the *LEP* to create prototypes, i.e. game levels. These levels are subsequently the object of analysis, together with participants' explanations and impressions of the activity.

The expected results of the analysis are gaining insights on integrating chemistry-related content into the *LEP* to consider features and pedagogies that could improve the learning experience. The assessment process pays special attention to identifying crucial game items and mechanics that facilitate the representation of chemical processes in a platform game. It is expected that, through the participants' expertise, the study reveals connections between game items and platform game mechanics in general with chemical engineering content.

4.6 Results

Three participants, P1, P2, and P3, completed a level and sent it together with explanations about what they intended to represent, as well as their impressions of the activity.

P1 created a brief level to represent the molecular combination of hydrogen (H_2) and oxygen (O) resulting in the molecular formula of water (H_2O) (fig. 20a, 20b, and 20c).

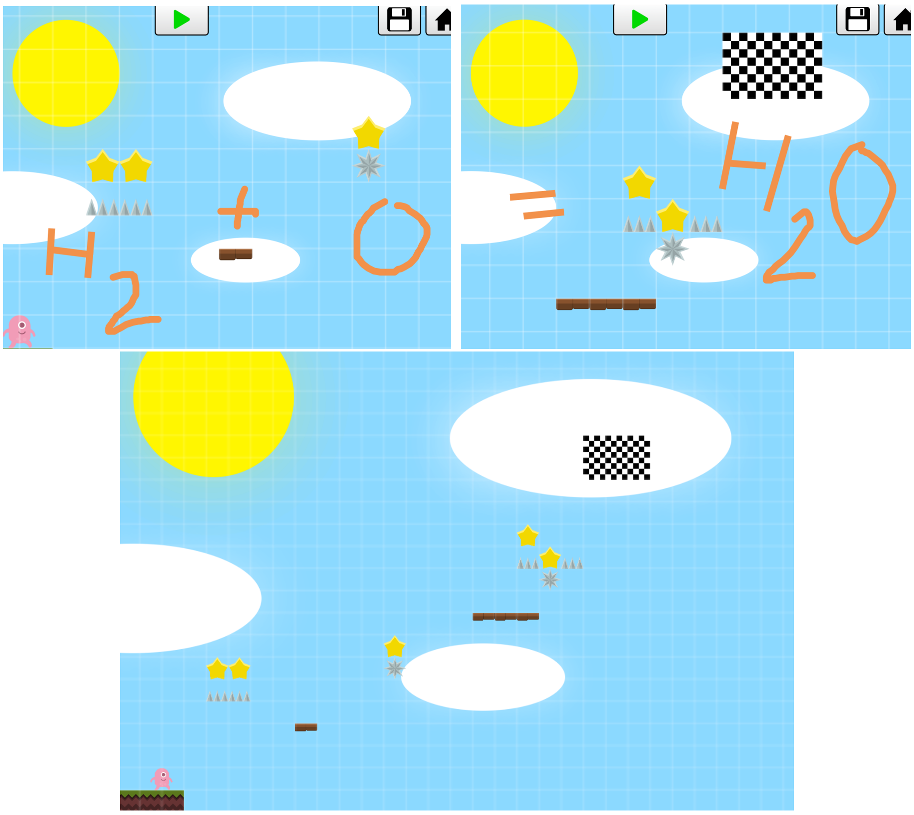


Fig. 20a, 20b, and 20c: Three images of the explanation and level proposed by P1.

In the level, P1 assigned some game items a molecular value. For example, the combination of 2 stars and two pairs of three spikes equals the molecular formula of hydrogen (H_2). To complete the level successfully, it is necessary to get all the stars that grant the avatar superpowers and can then survive the spikes to reach the chemical equilibrium, symbolised in the level by reaching the finish flag.

P2 created a level based on core factors of a chemical reaction (fig. 21). The number of coins on each platform represent the stoichiometry of the reaction and the height of each pile stand for the boiling point of each gas. The higher the tower, the more complicated it is to reach, which tries to indicate that the gas is more volatile.

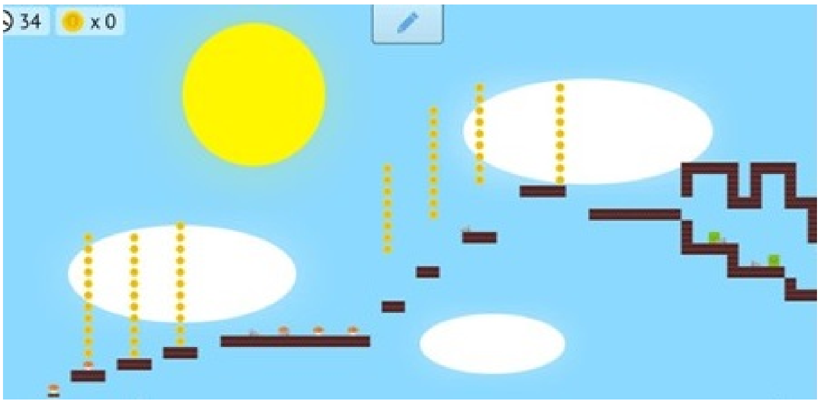


Fig. 21: Image of the level created by P2.

P2 mentioned that they were not creative enough to come up with an idea to use the game items that have a negative effect on the gameplay. They also regretted not having enough agency during the level creation to be able to create a system in each the game is over when players achieve a specific amount of coins, for example.

P3 presented a level that represented the production of acid citric on an industrial scale (figures 22a and 22b).

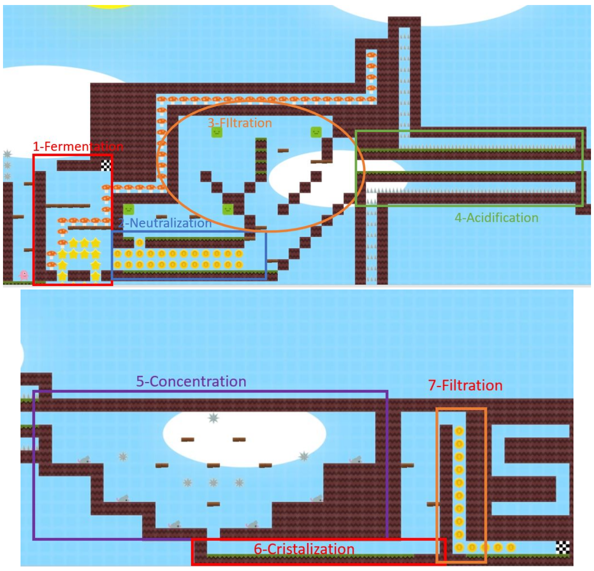


Fig. 22a and 22b: Two images outlining the level made by P3.

In the P3's level, there were seven different phases inspired by a real engineering process design of acid citric: fermentation, neutralisation, filtration, acidification, concentration, cristalisation, and filtration (fig. 23).

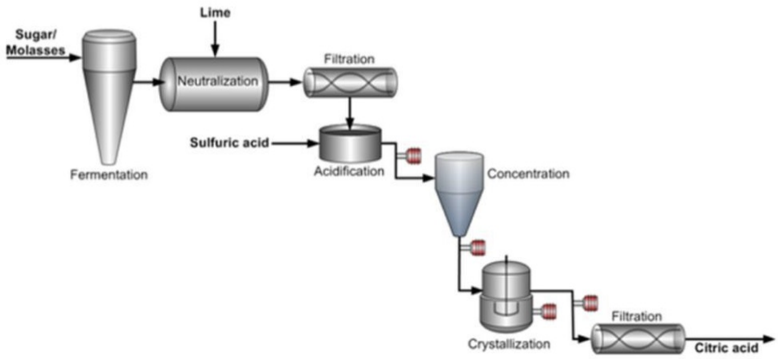


Fig. 23: The different phases of a real citric acid production process on which P3 based their game level. (*Image courtesy of Vaisala website*)

P3 commented that the number of pre-made items hindered them to represent all the different phenomena occurring during a process. They had to use the same game items for different purposes, which was confusing.

Another participant, P4, did not create a game level but sent a detailed document on suggestions to integrate platform games with chemical concepts. P4's idea of integrating chemistry into a platform game can be compared to P1's concept of assigning a molecular value to one or a group of game items to convey a message regarding chemical formulas. P4 included different variants depending on a reversible reaction, non-reversible reaction, or reaction that does not occur.

P1, P2, P3, and P4 coincided with the fact that they experienced some major limitations and changes in the editor, e.g. adding other pre-made items to choose from, which would certainly improve the user experience to a great extent. The two remaining participants, P5 and P6, did not understand how to represent their expertise to the editor, and so these participants did not make any level.

4.7 Discussion

Participants encountered major difficulties to create chemistry-related levels with the mobile application *LEP* and so the application cannot be used for the purpose of this investigation in its original form. Most participants agreed that the selection of pre-made items in the editor is too limited, which is why a new feature, through which new game items can be created, is incorporated (see 3.2).

It is observed that most participants were concerned with the appearance of the game items in the levels, while the interaction, i.e. how the items behave in the gameplay, was generally ignored. To attract participants to explore how game items interact in the editor, the new game items created with the new feature are limited to skins of pre-made items. That is, users can select the 2D image of their choice, but can only be assigned the existing interactions in the editor. Overall, this feature is expected to facilitate the integration of chemistry-related content in the levels while maintaining the challenge of assigning a meaningful or relevant interaction to new game items.

Two of the participants did not understand the activity or did not know how to use the editor, which signals that introductory guidelines must be considered. For a more inclusive activity, the guidelines should explain the main features of the editor so that participants who are not familiar with platform games and/or drag-and-drop editors can take part in the activity.

If game levels are associated with spaces in which the player experiences the game mechanics and rules (Smith et al., 2008, p. 75), the space in platform games seems quite fitting to represent structures such as engineering processes or phenomena related to them. Therefore, it is recommended to select engineering process design as the learning content in this investigation.

Finally, it is decided to develop the modified version of the *LEP* on a desktop application named G.E.L. instead of a mobile application for usability reasons. Using the computer is more convenient than a mobile phone to search for 2D images, which may involve some image editing, and to create new game items in the editor. Assuming that the levels will be made in teams and that at least one computer will be available per team, a larger screen is an advantage too when sharing a device.

4.8 Conclusion

A case study is conducted with six participants to test the applicability of platform game level editors with chemistry-related content.

Participants, with a background in either chemistry or chemical engineering, intended to create game levels with the *Level Editor for Platformers* to represent a chemical formula or the industrial production of acid citric respectively.

After analysing the results, two main hypotheses can be drawn. The first one is that the editor should incorporate a new feature through which new game items can be created. The feature intends to offer a balanced learning experience through which users can integrate chemistry-related images. However, the new items are limited to the existing interactions to maintain the challenge required by the activity.

The second hypothesis is that specific guidelines should be considered to guarantee that participants who are less familiar with platform game mechanics and editors understand the activity and can take part in it.

Chapter 5

STUDY TWO: THE PILOT STUDY

The second study in this investigation explores the cognitive effects of creating chemistry-related game levels. Building on generative learning theory (Wittrock, 1974), it is assumed that one of the cognitive advantages of the CHEM Jam is to encourage knowledge transfer since understanding in chemical engineering is transferred in a game. This hypothesis leads to analyse understanding through the lens of the resulting artifact, that is, a game level made with the G.E.L.

Through notions of intrinsic integrated educational games (Habgood et al., 2005a) and flow theory (Csikszentmihalyi, 1990), the analysis helps to associate Brüsow and Wilkinson's framework to assess concept maps (2007) with flowcharts. Flowcharts can be helpful to create chemistry-related platform games and are also fundamental elements of engineering process design courses.

Drawing on the previous associations, a tailored assessment methodology can be created to be used for facilitators of a CHEM Jam event. The assessment, which showed to be effective, is used to select the CHEM Jam winner in study three. Finally, the methodology is improved.

5.1 Aim

Generally, measuring learners' understanding in student-centered 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 the difficulties of assessment, this study aims to propose an effective assessment methodology that results from analysing a level created with the G.E.L. during a pilot study. The new methodology allows assessing chemistry-related platform game levels in line with different criteria and scoring.

5.2 Background

Wittrock's generative learning theory (1974), which proposed a new model of human learning based on the notion of transfer of knowledge, constitutes the baseline of this study case. His approach presents the grounds to integrate learners' prior knowledge with to-be-learned information, which in the present activity is used in favor of knowledge application and transfer.

Knowledge transfer is a key term in education because improves learning a new task through the transfer of knowledge from a related task that has already been learned (Roque et al., 2016). Knowledge transfer occurs when learners actively apply prior knowledge from one specific context to another context (Wittrock, 1974; Pea, 1987; Perkins and Salomon, 1994). For example, a roller skater will be able to learn ice skating faster than another individual who has never tried any type of skating before. This occurs because the roller skater can transfer existing knowledge into the ice skating modality.

Within an educational framework, proposing activities that force learners to transfer knowledge is an encouraging practice to improve learning. In addition to that, the process is an evident sign that learners have understood the content. This is particularly relevant in the case of engineering education because by applying prior knowledge in new contexts students practice a deductive approach, which can be useful to come up with creative solutions to engineering problems (Schneck, 2001; Ellis et al., 2005; Thomas, 2007).

As opposed to precedent transfer models of instruction in which the instructor is assumed to be the distributor of knowledge and skills, the CHEM Jam's structure facilitates a learner-centred pedagogy that promotes learners' transfer of knowledge. That is a learning process through which new knowledge about game design is acquired in the introductory stage, prior knowledge about chemical processes is applied in stage one, and new and prior knowledge is integrated into a platform game level that is presented in stage two. This type of transfer occurring during the CHEM Jam is classified by Hung

(2013, p. 29) as *far transfer*. As opposed to *near transfer*, *far transfer* refers to a low degree of similarity and relevance between the original context in which knowledge was learnt, i.e. chemical engineering, and the new context in which the knowledge is applied, i.e. a platform game level.

Platform game levels and how content is structured or the message conveyed in the levels can be compared to mapping activities, a learning strategy to promote generative learning (Fiorella and Mayer, 2016). Mapping consists of organising texts and/or images into conceptual structures and connections among the core items, e.g. concept maps. The technique requires to a great extent learners' abstraction and organisation skills, which has significantly benefited active learning and overall learners' understanding as shown by several empirical studies (Holley et al., 1979; Chularut and DeBacker, 2004; Surapaneni and Tekian, 2013; Machado and Carvalho, 2020). It is argued that the CHEM Jam has similar effects than a mapping activity because the CHEM Jam encourages the transfer of engineering knowledge in a new conceptual structure such as a platform game level.

5.3 Procedures

In February 2021, a two-day pilot study was conducted online[1] with two graduate students in chemical engineering from KU Leuven, Belgium. Even if a small level sample resulted from this study, the approach chosen produced thorough data to consider an efficient assessment methodology after examining the results.

On the first day, participants attended an introductory session about platform games and game level design, which tried to offer complimentary information and guidance for non-game designers as per the results of the previous study. Participants were asked to create one platform game level with the G.E.L. to represent, in a creative way, the solution to the following mathematical problem:

0.40 mol of nitrogen and 0.96 mol of hydrogen are placed in a 2.0 L container at a constant temperature. The mixture is allowed to react and at equilibrium, the molar concentration of ammonia is found to be 0.14 M. Calculate the equilibrium constant, K_c*, for the reaction:*

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$ [2]

During the introductory session, participants were offered a level example with a

[1]The activity was carried out online to comply with the restrictions and limitations in place by the Danish authorities due to the COVID pandemic in 2021. Given the circumstances and the increased complications to attract students to participate in online tests voluntarily during the pandemic, a larger-scale study is planned for the third study (chapter 6).

[2]*The equation indicates that a reversible chemical reaction combining nitrogen and hydrogen forms ammonia.*

3-step guide to ease the creation process. They were advised to start selecting, from random, free images publicly available online, a flowchart representative of the proposed theme, i.e. industrial ammonia production. Figure 24 was given as an example of a flowchart outlining ammonia production.

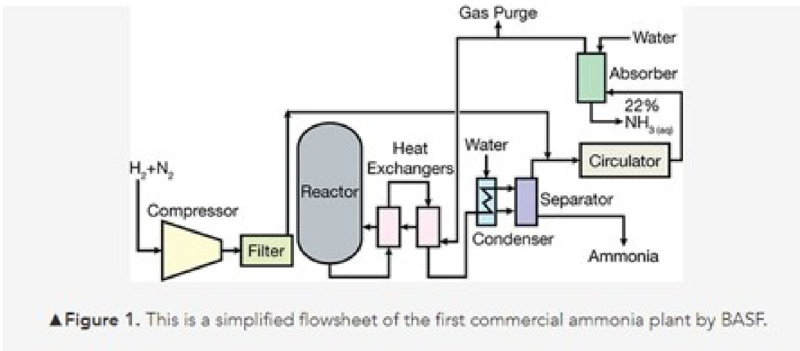


Fig. 24: Flowchart example shown to participants for inspiration. (*Image courtesy of AiChE website*)

The second step in the 3-step guide was choosing the 2D images that had to be used as the appearance of the new game items to create in the editor. Next, new game items should be assigned a type of interaction, before being created and saved in the level that participants were making (fig. 25).

Fig. 25: Examples of new items' skins representing equipment necessary for industrial ammonia production: compressor, filter, and reactor.

The last step indicated that participants must combine existing and new items to create the level. A level example was shown (fig. 26) with pre-existing items and the new items that were previously skinned.

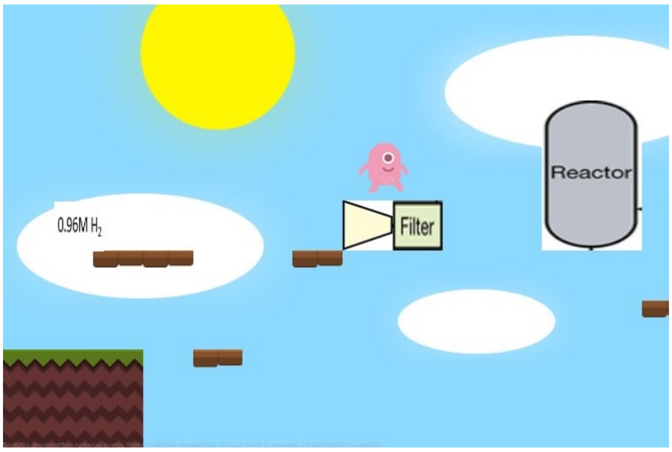


Fig. 26: Image of the level example provided during the pilot study showing existing and new items, as well as the avatar in pink.

After the introductory explanation and suggestions, participants downloaded the G.E.L. and created a game level. On the second day, students presented and explained the level that they had created with the G.E.L.

5.4 Methods

A qualitative thematic analysis (Boyatzis, 1998; Roulston, 2001; Braun and Clarke, 2006) was conducted to analyse the data source, i.e. a recorded video in which the two participants share and explain the created level during a conference call.

The resulting level was first coded with ATLAS.ti (Muhr, 1991), a program designed for qualitative thematic analysis. Rather than just the game level, the video including the presenters' comments, is the actual data source of this study. The presenters' explanations provide additional information necessary to understand the functionalities of certain game items or actions in the level and, consequently, to be able to appropriately consider all the intended nuances when coding the level.

Based on the codes found, the pattern identified helped create an adequate assessment methodology for the levels. Subsequently, the pilot level was assessed with the methodology to test its applicability.

5.5 Resulting level

The participants created a level that represented ammonia production on an industrial scale. The level showed a combination of physical phenomena and equipment that typically occur or are necessary to originate a chemical reaction that produces ammonia. More specifically, the new game items represented elements related to pressure, catalysts, a reaction vessel, and temperature. The final part of the level showed the resulting ammonia applied as fertilizer.

The sections about pressure (fig. 27), catalysts (fig. 28), and temperature were represented with two game items each that showed opposed behaviors in the gameplay to imply that the play had to make certain decisions to depict an efficient engineering process while playing.

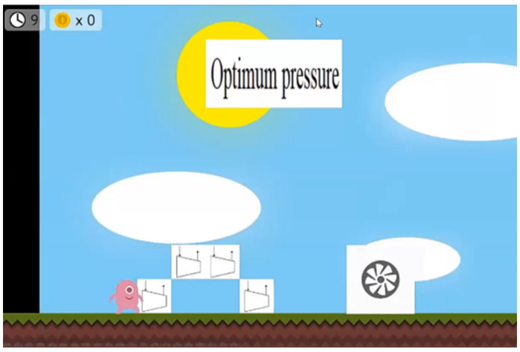


Fig. 27: Pressure represented in the resulting level.

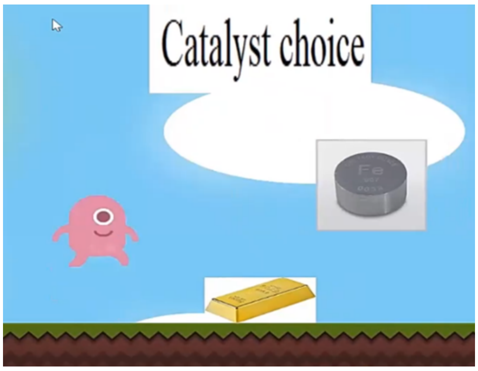


Fig. 28: The catalyst phase represented in the resulting level

In the section about pressure, four compressors were assigned a coin interaction, whereas 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. The interactions imply that compressors, which increase the pressure, are necessary and the turbine is not to reach the optimum pressure to favor the chemical reaction.

In figure 28 two types of catalysts are represented: a catalyst made of iron and another made out of gold, interacting as a mushroom and a spike respectively. The type of catalyst used for industrial production is the iron catalyst, which is why its game item impacts positively the gameplay. Iron catalysts are used to reduce the activation energy of the reaction and make the reaction go faster.

5.6 Thematic analysis

The explanatory video about the level was analysed thematically to identify the codes in figure 29.

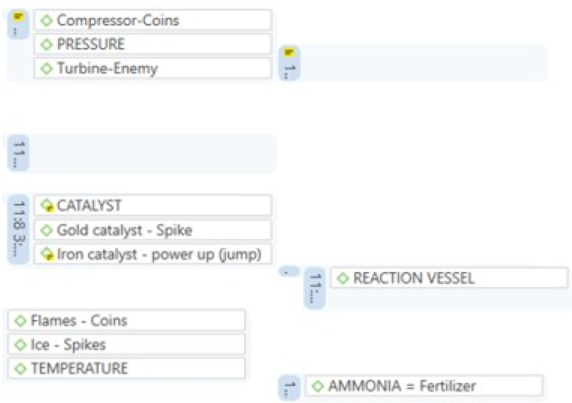


Fig. 29: Codes found in the level's thematic analysis with ATLAS.ti

The pressure, catalyst, and temperature phases in the level include game items rewarding or punishing the player's behaviour in accordance with what should occur with some phenomena and what industrial equipment should be used for the chemical reaction that produces ammonia to happen.

The reaction vessel in which the actual reaction is occurring, as well as fertilizer, i.e. ammonia applied as fertilizer, are represented in the level but these game items are not assigned any interaction and, therefore, are not significant representations for this analysis. Out of the codes found in the representations of the reaction's pressure, catalyst, and temperature, a pattern is identified (fig. 30).

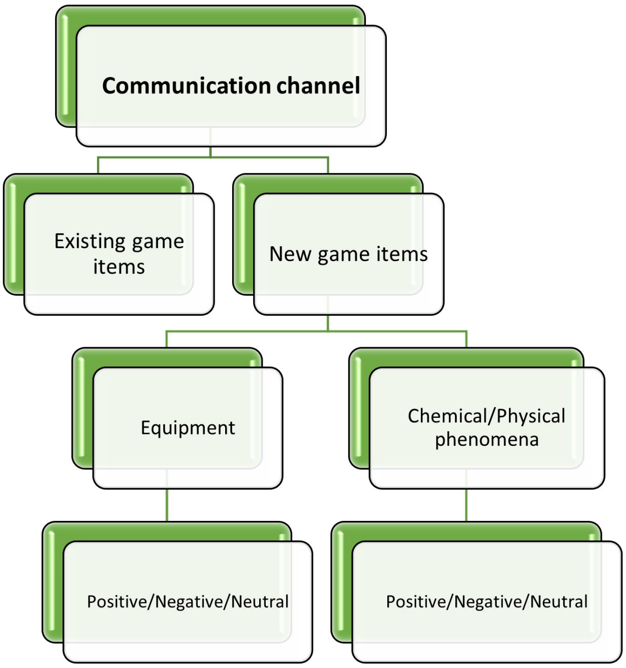


Fig. 30: Pattern identified after coding the level.

The pattern shows that images related to physical phenomena and equipment involved in chemical engineering processes can be used to skin the game items in the levels. Game items in the level communicate relevant information about chemical processes through the item's behaviour in the gameplay, which can be positive, negative, or neutral. Hence, through the interactive items, the learning content is integrated intrinsically into the game because the integration occurs on a visual and interactive level (Habgood et al., 2005a; Habgood et al., 2005b).

Educational games that present intrinsically integrated content benefit from the flow of the game experience because the learning material is discovered through the core mechanics of the game (Jacob Habgood and Ainsworth, 2011, p. 173). The notion of game flow is an application of Csikszentmihalyi's psychological theory of flow (1990) which argues that individuals can achieve a state of flow, referred to by the author as "an optimal experience that brings joy, creativity, and a total involvement with life" when one's attention is focused on realistic goals that match their skills (Csikszentmihalyi, 1990, p. 16-17).

The game flow is achieved when the game design offers a balanced player experience that is neither too difficult, which would cause anxiety to players, nor too easy and causing boredom. This pattern has been represented graphically by Csikszentmihalyi (1990, p. 96) to show the conditions for flow to occur (fig. 31).

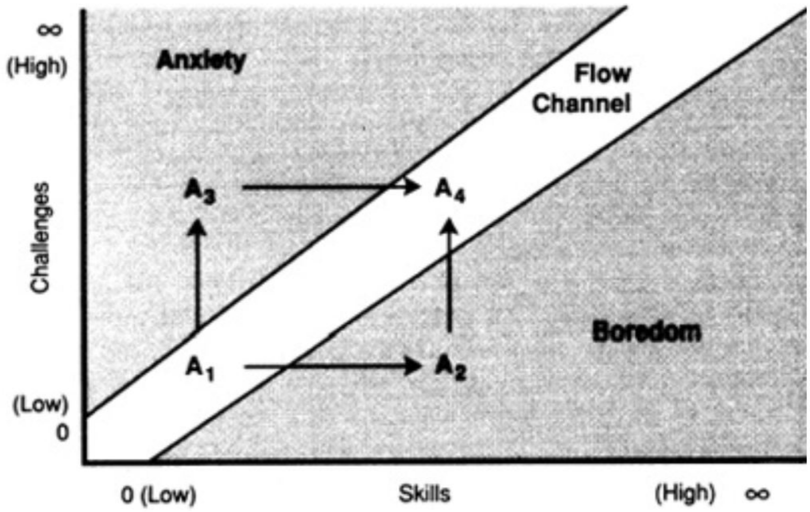


Fig. 31: Graphical representation of the conditions for flow to occur (Csikszentmihalyi, 1990, p. 96)

To complement the arguments and examples of flow activities included in Csikszentmihalyi's book, several studies have shown the cognitive and motivational efficacy of his theory in intrinsically integrated educational games (Jacob Habgood and Ainsworth, 2011; Echeverría et al., 2012; Denham, 2016; Ke, 2017; Shi et al., 2022).

The notion of creating educational games intrinsically integrated has been useful for this investigation to understand the role of flowcharts when creating platform game levels and consider how chemistry-related platform games should be structured. The flowcharts provide visual information about industrial equipment, physical phenomena, and how they interact during a chemical engineering process that, together with learners' prior knowledge, can support the structure of the levels and appearance of the new game items. This is particularly relevant for this investigation because process flow diagrams, a specific type of flowcharts, are graphical representations widely used in engineering process design courses that can represent the baseline to integrate the CHEM Jam in curriculum-based engineering education.

5.7 Original assessment methodology

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; Brüsow 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 can easily relate to engineering process flow diagrams, Brüsow and Wilkinson's framework to assess 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 have been modified for the purpose of this study in figure 32.

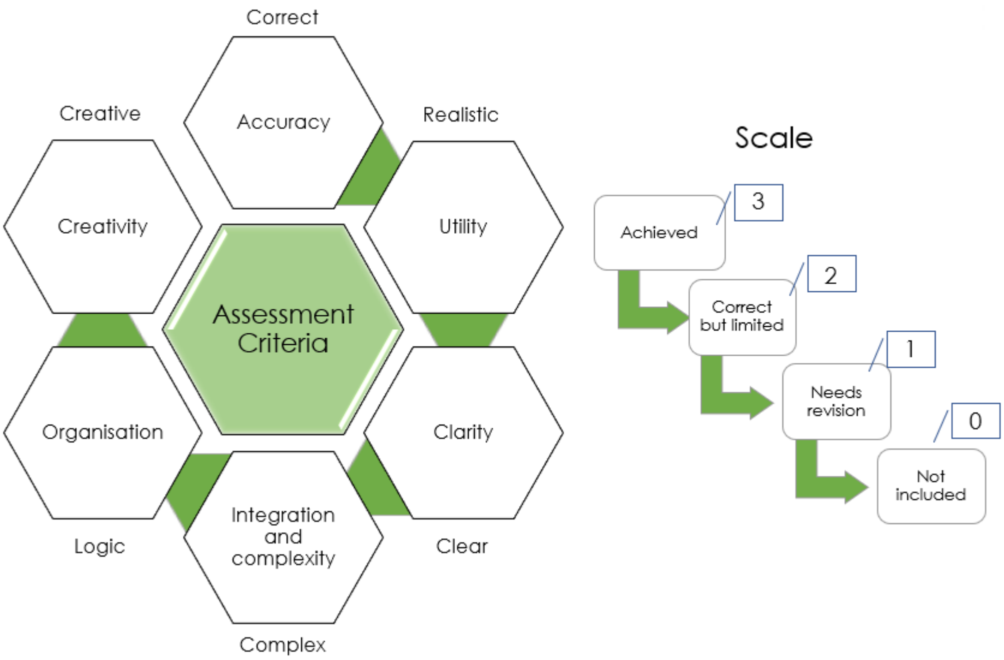


Figure 32: Assessment framework including the assessment criteria (left) and the scoring scale (right).

The resulting methodology 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 reflected in the level is correct, limited, incorrect, or simply missing by giving a 3, 2, 1, or 0 scores respectively (figure 32).

Utility can be used to grade to what extent the level is realistic for a chemistry-related course following the same assessment scale as the previous category, as is the case for all the categories in this methodology. The grade on how clear the content involved in the level is, the category *clarity* is applied. 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 or not will be informed by the category named *organisation*. Finally, the last category *creativity* evaluates how the learning content is approached and integrated with the new game items in the level.

5.7.1 Pilot study

The proposed framework was applied to the level resulting from the present pilot study. Five Ph.D. 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 figure 32 for their assessments.

The results show that this methodology allows to efficiently provide constructive feedback about the artifacts created during the CHEM Jam from a chemical engineering perspective (table 3).

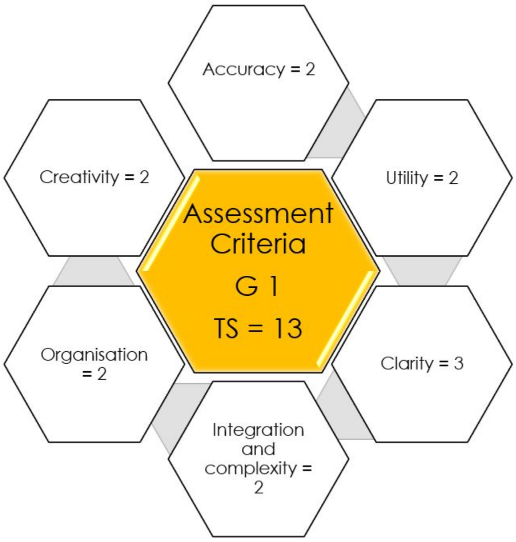
Criteria	Achieved (3)	Correct but limited (2)	Needs revision (1)	Not included (0)
Accuracy	1	3	1	0
Utility	3	0	0	2
Clarity	3	1	1	0
Integration and complexity	2	2	1	0
Organisation	2	2	0	1
Creativity	5	0	0	0

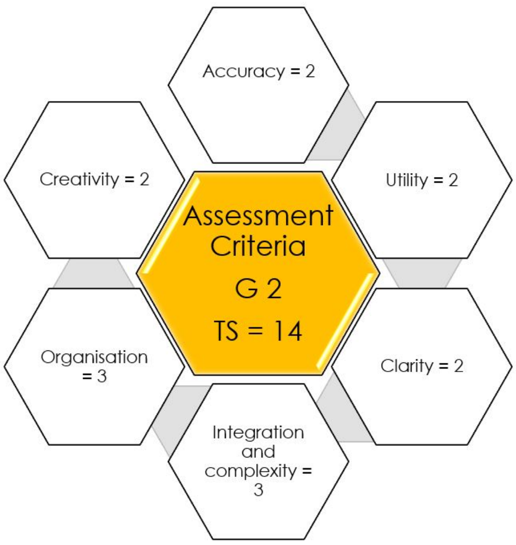
Table 3: The scoring of the pilot study's resulting level.

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 figure 32 to evaluate whether the experience is relevant for a chemistry-related course. Finally, the grades of one of the assessors were based on the resulting level in isolation. So, the assessor 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, their scores ranged from *Need revision* to *Not included*, except for the creativity category.

5.7.2 CHEM Jam

The methodology was used at a later stage to assess the levels presented during the CHEM Jam event in process design, an intervention addressed in chapter 6.





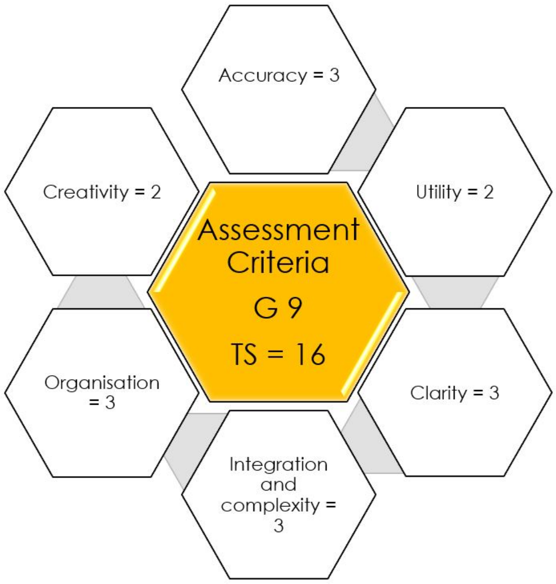


Fig. 33: The scores given to groups 1, 2, and 9 for their levels presented during the CHEM Jam event.

Group 1 received 2 points in the category *accuracy* because the images of the heat exchangers were not correct. In *utility*, they were given 2 points too since overall the process design that the group tried to represent was relevant to the course, but the recycling process was missing in their level.

The learning content was quite clearly represented, so it scored 3 points in *clarity*. However, the level could have addressed other, more complex chemistry-related phenomena, which is why the team received 2 points in *integration and complexity*. Since the stream flow of the process in the recycle phase was not clear, group 1 received 2 points in *organisation*. Finally, it was considered that the level could have been more creative, such as being more thorough in the way unit operations were represented or approaching process design from another perspective, i.e. the product's change of state, so this group scored 2 in *creativity*.

Group 2 presented a level in which the pictures of the new game items were exactly the same icons used in their Process Flow Diagram. The images looked overall quite small and low quality in the level because the pictures were directly copied from the digital version of the process flow diagram. Therefore, the group received a 2 in the categories *clarity* and *creativity*. There was room for improvement in *accuracy* and *utility* and so the level scored 2 points in each one. Finally, since the content was presented in a logical manner and addressed the main unit operations of the process, the group received 3 points in both *organisation* and *integration and complexity*.

Group 9 presented a game level with clearly and thoroughly explained content that scored 3 points in all the categories except for *utility* and *creativity*. The assessor considered that the avatar in the gameplay video did not follow the logic stream for recycling, which is why the team did not receive the 3 points for *utility*. In terms of *creativity*, the team presented a particularly original feature with the learning content integrated with the avatar's change of state, from bigger size to smaller size (3.5.2). However, some of the images to skin new game items were the same images used in the level that was presented to participants as an example, which is why group 9 scored 2 in the *creativity* category.

Ultimately, group 9 was the team that received the highest score, 16 points, and, therefore, the group was declared the winner of the CHEM Jam.

5.8 Final methodology

After conducting the CHEM Jam intervention, it was observed that some categories of the assessment framework used to give constructive feedback during the stage two of the event, did not align correctly with the learning outcomes of the process design course into which the CHEM Jam was integrated. Additionally, the optimisation of process designs regarding ethical, safety, environmental, and economic aspects, which is a relevant part of the course, had not been included in any of the assessment criteria.

Based on the mentioned issues, the assessment methodology was improved and compiled the different criteria into four categories (figure 9 in chapter 3). The new categories evaluate if the levels effectively include the processes' stream flow, the main unit operations, optimisations in terms of ethics, safety, sustainability, and economy, as well as the degree of creativity. A comprehensive table including the scoring following this improved methodology of all the levels created during the CHEM Jam intervention can be found in appendix A.

5.9 Discussion

The resulting level of the pilot study shows that participants successfully presented a platform level in which their expertise in chemical engineering was included creatively. Thus, the activity can be part of an engineering course to foster collaborative learning, reflection, and creativity. Particularly, the structure of platform games can be associated with flowcharts. Designing flowcharts is a generalised practice in engineering education to learn process design. This means that the possibility to integrate a CHEM Jam in a process design course as part of the chemical engineering curriculum should be explored.

An example to integrate the creation of platform game levels into engineering education can be proposing that participants use their own flowchart previously produced as part of a chemical process design course. This type of integration involves that learners would benefit from prior knowledge in process design acquired during the course. Overall, the activity can encourage learners to transfer that knowledge into a platform game through a reflective task, in line with some knowledge transfer theories.

Previous studies have highlighted the challenges to measure learning in game jams (Arya et al., 2019; Hrehovcsik et al., 2016; Meriläinen and Aurava, 2018, p. 33), which also applies to most of the practices mainly based on learners' agency and exploration. However, the assessment framework presented in this paper resolves two main issues. Firstly, the effective applicability of the framework demonstrates not only that learning in chemical engineering processes occurs when creating chemistry-related platform levels, but also that learning can be further encouraged 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. The criteria will serve to select the winner of the CHEM Jam. But, most importantly, by informing participants about the levels' scoring system, the content in the levels is adjusted to the learning objectives without putting the exploratory aspects of the experience at risk, as can occur if instructions are too explicit.

Flowcharts offer participants some structural and representational indications for the game levels which, despite offering guidance, do not spoil the exploratory essence of the activity. Maintaining the integrity of the exploratory aspects of the CHEM Jam is particularly relevant because it is assumed that most of the reflective work, and hence learning, is occurring through exploration.

5.10 Conclusion

A pilot study with the first prototype[3] of the G.E.L. was conducted online in February 2021 with two undergraduate students in chemical engineering from KU Leuven, Belgium. Participants created a platform game level representing phenomena and unit operations of an engineering process that aim to produce ammonia.

After a qualitative thematic analysis of the created level, a framework is produced to assess this kind of game levels. The framework is inspired by the representational similarities between concept maps and flowcharts. Flowcharts are broadly used to create engineering process designs. The pattern drawn from the thematic analysis indicated that physical and chemical phenomena and industrial equipment were integrated intrinsically and pointed towards using flowcharts to help students create intrinsically integrated levels.

[3]Some minor bugs in the G.E.L. were reported by this study's participants. The bugs were fixed and the second prototype of the G.E.L., for Windows and macOS, is used in this investigation's third study.

Five colleagues of the CHARMING project assessed the resulting level with the assessment framework previously produced. The activity aimed to verify the applicability of the framework in chemistry-related platform levels. The results showed that the assessment is an effective tool to measure the learning material of chemistry-related platform game levels.

The final part of this study case addresses how the assessment methodology was used to assess levels created for the CHEM Jam. The scoring system not only provided constructive feedback to participants but also determined the winner of the CHEM Jam (chapter 6). Finally, an improved version of the assessment was considered. The assessment needed some modifications to propose effective criteria in line with the learning outcomes of the mandatory course in process design at DTU as explained in chapter 3 of this investigation.

Chapter 6

STUDY THREE: THE CHEM JAM IN PROCESS DESIGN

This chapter addresses an intervention during which a CHEM Jam was integrated into a process design course, a mandatory course in the bachelor in chemical and biochemical engineering at Danmarks Tekniske Universitet (DTU). The intervention aims to explore principally the motivational and social outcomes of conducting a CHEM Jam in curriculum-based education.

6.1 Aim

This study aims to measure the intrinsic motivation of participants who attended a CHEM Jam event. The event, conducted at DTU, was based on the hypothesis that game jams provide plenty of opportunities to make participants feel competence, relatedness, and autonomy (Filak and Sheldon, 2003; Monteiro et al., 2015, p. 435; Grey et al., 2018) due to the playful nature of these events. The playful nature of game jams is mainly based on the argument that a game jam is ultimately a game to make games, which has been addressed in 2.3.2 of this investigation.

Another aim of the intervention described in this chapter is to explore the CHEM Jam's social effects from a collaborative learning perspective. Finally, besides the motivational and social outcomes, this chapter discusses other types of effects resulting from conducting the CHEM Jam within an undergraduate engineering course.

6.2 Background

The intervention addressed in this chapter sets out on the self-determination theory (SDT), a theory in psychology about human motivation, development, and well-being (Deci and Ryan, 1985). Deci and Ryan (1985) distinguish specific motivators in human behaviour that play a fundamental role in human development. SDT's advocates argue that these motivators were overlooked by previous theorists involved with development processes, like, for instance, Piaget, and that educational practices must be revised considering intrinsic and extrinsic motivators.

On one hand, intrinsic motivation is a type of human motivation differentiated by the SDT that Ryan (2009, p. 1) defines as a "natural tendency manifest from birth to seek out challenges, novelty, and opportunities to learn". Intrinsically motivated learners experience benefits in their self-motivation, social development, and personal well-being, which may have a positive impact on these learners' understanding (Deci and Ryan, 1985).

Extrinsic motivation, on the other hand, implies "doing an action moved by a separable outcome" (Ryan and Deci, 2000a, p. 55), e.g. participating in an event motivated by a financial reward. Since extrinsic motivators undermine intrinsic ones, this study is focused on factors that motivate learners intrinsically rather than extrinsically.

To facilitate the optimal functioning for intrinsic motivation, Ryan and Deci (2000a) identify three essential psychological needs in individuals: competence (Harter, 1978; White, 1963), relatedness (Baumeister and Leary, 1995; Reis, 1994) and autonomy (DeCharms, 1968; Deci, 1975). This means, for instance, that a learner who feels an increase in their competence will equally feel intrinsically motivated toward an end. More precisely, a sub-theory of the SDT, the Cognitive Evaluation Theory, suggests that social environments can increase people's intrinsic motivation by satisfying the three mentioned needs (Ryan and Deci, 2000b, p. 71). That argument is extended by some studies showing how learner-centred environments that support learners' autonomy, rather than controlling learners, foster intrinsic motivation, curiosity, and desire for a challenge in learners (Deci et al., 1981; Ryan and Grolnick, 1986; Flink et al., 1990).

An additional aim of the intervention described in this chapter is to explore how collaborative learning occurs during the CHEM Jam. In this study, collaborative learning is understood as "a situation in which two or more people learn or attempt to learn something together" which is the definition discussed in the introductory chapter *What* *do you mean by collaborative learning?* by Dillenbourg (1999). Collaborative learning is a fundamental part of the CHEM Jam that reinforces the learning experience, building upon Vygotsky's (1978) social constructivism, Shaw (1995) and other related theorists that advocate for the benefit of social interactions, and cooperative efforts to learn, understand and solve problems (Inaba and Mizoguchi, 2004, p. 286).

A main theoretical foundation of collaborative learning leans on the theory of social interdependence. Social interdependence occurs when individuals share common goals and each one's success depends on other's actions, like in cooperative and competitive learning (Deutsch, 1962; Johnson and Johnson, 1989). Contrarily to other learning modalities, such as the individualistic or competitive approaches (Johnson and Johnson, 1996), collaborative learning offers a "nurturing environment" (Panitz and Panitz, 1998, p. 172) that includes peer-to-peer interactions and collaborative tasks, instead of individualistic efforts, and promotes a common success that does not involve others' failure.

6.3 Procedures

The intervention was conducted on four non-consecutive days during the winter semester of 2021 at DTU. The event was part of the process design course, a mandatory course for the bachelor degree in chemical and biochemical engineering.

To attain the main learning objectives of the course, which are thoroughly explained in the subsection 3.5.1 of this investigation, the students must develop a process design concept for cumene production that includes main unit operations to which mathematical, physical and chemical principles must be correctly applied. In addition to that, a process simulator (PRO/II) must be efficiently used to anticipate and resolve future problems in the students' concepts.

6.3.1 Introductory stage

The introductory stage of this intervention was organised in form of a lecture in the students' regular classroom of the DTU's process design course on 21/09/2021. The CHEM Jam event was presented as an optional activity to the 48 students enrolled in the course that semester. To stimulate the participation rate, it was announced that the course manager would consider positively including a game level in the oral exam.

During the introduction of the CHEM Jam, the three stages of the activity, i.e. introductory stage, stage one, and stage two, were explained. To facilitate the creation of game levels related to the content of the course, students were given a set of guidelines.

The first step in the guidelines recommended using the process flow diagrams (PFDs), generated by PRO/II, from their conceptual designs to consider the architectural design and main elements of the level.

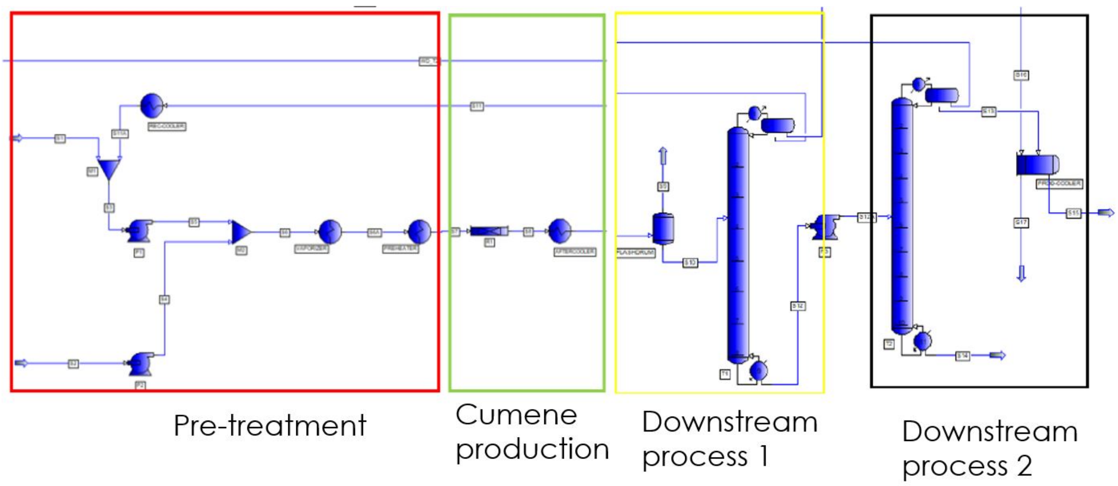


Fig. 34: Process flow diagram submitted as a part of a group assignment the previous year.

The PFD in figure 34 is part of the conceptual process design of cumene production that a group of students submitted as a work assignment for the course the previous year. The design submitted included four main phases in the process: pre-treatment, cumene production, downstream process 1, and downstream process 2.

Due to the structural correlation between the PFDs and platform game levels, students could opt to include a game level in the presentations for the oral examination, which was a group examination. The levels could be used instead of the PFDs to creatively show and explain their process design concept and could be combined with additional information, e.g. slides explaining relevant calculations.

The next step of the guidelines focused on the unit operations included in the pre-treatment phase of the diagram (fig. 35):

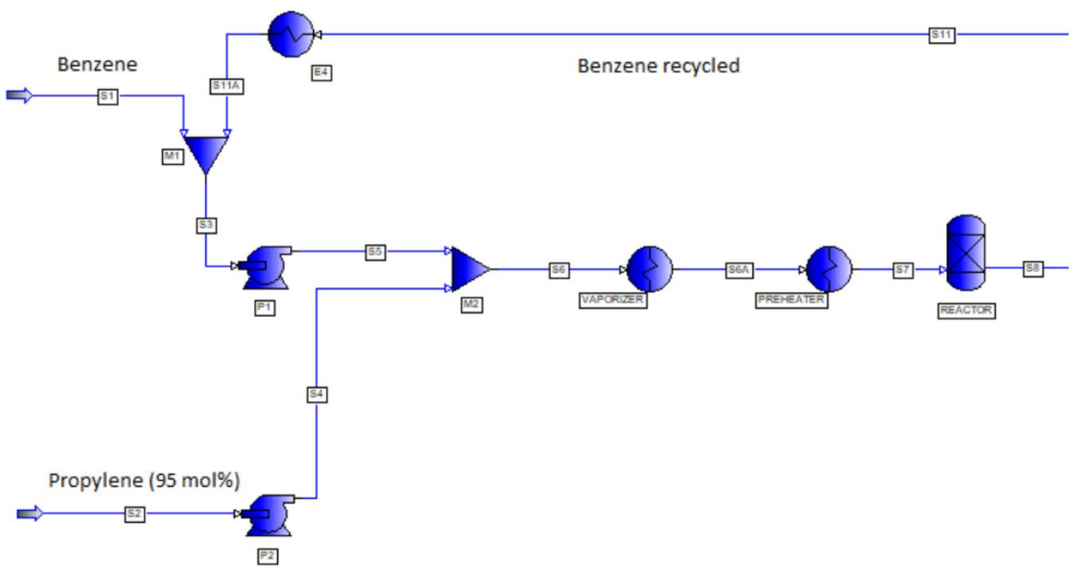


Fig. 35: Detail of the unit operations included in the pre-treatment phase of the design concept example.

Students were asked to include all the phases of their design concept in the game level, even if the guidelines only included the pre-treatment phase as an example.

The main unit operations in the pre-treatment phase were identified, as well as other game items necessary to construct the level. A 2D image was selected to skin each one of the elements that needed representation in the game level. Some of the images selected were, from left to right in figure 36, the mixer tank M1, the other mixer M2, stream flow indicators for benzene and for a mixture product respectively, a tubular air pre-heater, and a plug flow reactor.

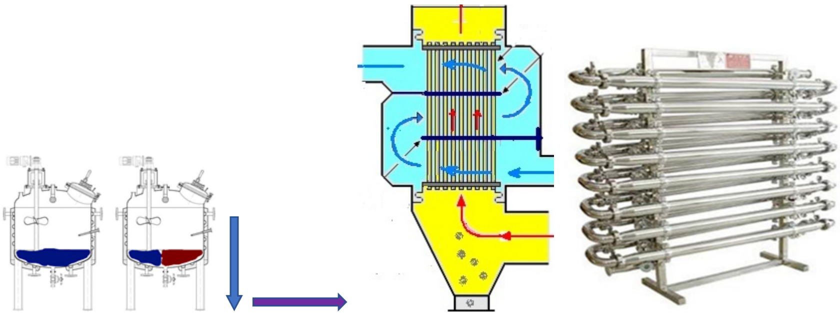


Fig. 36: Some of the 2D images selected to skin new game items in the level example to represent unit operations and other elements in an engineering process design.

After selecting all the necessary images, students must decide how to structure the game level and which interaction will be assigned to each game item. Lastly, new game items can be created in the G.E.L. to design the desired level afterward.

The last step of the guidelines included a video of a level example to represent the pre-treatment phase previously analysed (fig. 37).

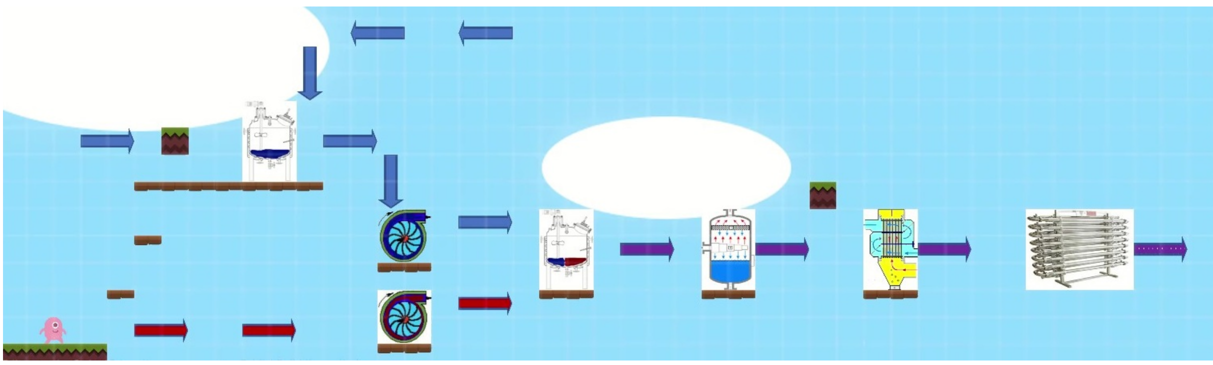


Fig. 37: Overview of the level example presented to students during the intervention.

As the pre-treatment phase, the level example, which combines pre-made with new game items, represents how benzene product is recycled with the stream flow (blue arrows) on the top of figure 37 that point to the left. The recycled product is mixed with new benzene and, after that, the resulting mixture is mixed with propylene, which is represented in the level with red arrows. Both propylene and benzene are pumped with two different centrifugal pumps before getting into the mixer. Next, the stream flow mixture, marked in purple, goes through a flash tank, a pre-heater, and a reactor.

The level example has been designed to offer a balanced player experience. First-time players, who will not be familiar with the game, should be able to progress adequately by facing challenges that are neither too easy nor too difficult in line with game flow theory (Csikszentmihalyi, 1990) as explained in chapter 5. If challenges in the levels are too easy, players will get easily bored. Similarly, players will feel frustrated if they continue failing when trying to go through the obstacles in a game level. As a rule of thumb when designing levels with the G.E.L., the game items in the level example must combine positive, negative, and neutral behaviours in a balanced manner. For instance, centrifugal pumps are power-ups that are conveniently placed before an enemy, in form of a mixer in the level. Thanks to that positioning of game items, the avatar can get an extra life before facing the enemy to last longer alive in the game, which overall makes the player experience less frustrating and more rewarding.

The level example is presented to students with the intention to produce an inspirational effect. Students are encouraged to be creative when designing levels, and design based on their own interpretations, using the interactions and integrating the learning content differently than in the level example, if possible. The CHEM Jam expects students to come up with new and creative combinations of game items, interactions, and learning content.

Next, students downloaded the G.E.L. on their computers, tested it, and familiarised themselves with the game mechanics and editing features to create game levels. During this familiarisation phase, it was reported that the Mac OS version of the G.E.L. could not be launched due to an error. The issue causing the problem could not be solved immediately, but the Mac OS prototype of the G.E.L. was functional for the CHEM Jam's next stage.

6.3.2 Stage one

The stage one, during which participants created the levels collaboratively, was held on 20/11/2021 from 10:00 to 14:00. The chosen venue of the event was a spacious lounge-style room at DTU's premises in Lyngby (Denmark) in which different office materials and technological devices were available, e.g. boards, or two TV screens. At 12 pm, pizza and soda drinks were offered to all attendees.

The room has the capacity to accommodate around fifty people. Out of the 48 students enrolled in the course, 22 students participated in the event, representing eight of the twelve groups of the course. Since the event was organised during the weekend, the activity was initially perceived by students as extra work in the course plan. To alleviate any negative perception of the activity and encourage participation, it was announced that students, who normally work in teams of three to five members throughout this course, were allowed to participate in stage one even if all the members of the same team were not present. However, it was advised that at least two members of each team should take part in the activity to ensure that the team could benefit from learning collaboratively.

Teams with four or more members attending the event were recommended to split into two teams to work separately on different game levels. This way, the teams could compare, discuss and choose the final proposal that best fits the message that they want to convey.

The assessment criteria that were applied to choose the winner in the next stage of the event were presented to participants (fig. 38). The criteria were based on the original assessment methodology that resulted from the investigation addressed in chapter 5.

Fig. 38: Presentation of the assessment criteria based on which the winner of the event was selected in stage two.

The assessment, based on six different evaluation criteria, i.e. accuracy, utility, clarity, integration and complexity, organisation, and creativity, is explained in section 5.7 of this investigation.

6.3.3 Stage two

Five teams tried to present their levels on 30/11/2021, but two of them arrived when the presentation session had ended and they could not present their work.

Groups 1, 2, and 9, as per the group number assigned for the course, presented their levels and received a total score of 13, 14, and 16 respectively. These scores are included and commented on in chapter 5 since the cognitive outcomes of the CHEM Jam are specifically addressed in that chapter.

6.3.4 Oral exam

For this study, participants were given the chance to present their game levels as additional information to the group-based oral exam on 14/12/2021. From the 12 existing groups in the course, 9 groups included a game level in their presentations.

The levels presented for the oral exam, which are available in Appendix C, were assessed a posteriori with the improved assessment methodology that has been presented in subsection 3.5.1 of this investigation.

6.4 Methodology

A mixed methodology of quantitative and qualitative methods was used to measure and analyse fundamentally the motivational and social effects of the CHEM Jam on its participants.

6.4.1 Quantitative methods

Instrinsic Motivation Inventory

The Intrinsic Motivation Inventory (IMI) is an assessment tool grounded on the SDT to measure the subjective perceptions of participants taking part in an activity (Ryan et al., 1983; Ryan et al., 1989; Grolnick and Ryan, 1987). The IMI is a likert-type rating scale that can give quantified insight into participants' attitudes based on seven different dimensions, referred to as subscales: interest/enjoyment; perceived competence, effort /importance, pressure/tension; perceived choice, value/usefulness, and relatedness (Ryan, 1982; Plant and Ryan, 1985; Markland and Hardy, 1997).

The subscale interest/enjoyment is considered the questionnaire that assesses specifically intrinsic motivation, even if the name given to the group of different subscales, Intrinsic Motivation Inventory, can be misleading. Since the present study seeks to explore intrinsic motivation as overall perception during the CHEM Jam event in comparison to perceived usability and participants' manifestations, other IMI's subscales, e.g. competence or relatedness, were discarded for this study's questionnaire, even if those subscales are closely related to psychological needs for individuals' intrinsic motivation.

In addition to the interest/enjoyment subscale's questions, CHEM Jam participants were asked to complete the value/usefulness questionnaire. It is argued that students' intrinsic motivation will largely depend on how students perceive the value/usefulness of the activity. This is particularly important when introducing an activity that a specific audience may not be familiar with, such as making games for learning chemical engineering, because participants' perceived motivation can easily decrease if participants are confused about the real value/usefulness of the activity.

The questions in both questionnaires were constructed to accommodate specifically the CHEM Jam context within the acceptable changes to maintain the validity of the questionnaire.

SUS questionnaire

The System Usability Scale (SUS) is a pre-approved questionnaire to measure how people perceive the usability of a digital artifact (Brooke, 2013). Perceived poor usability of the G.E.L. would difficult the game level creation and, hence, have a direct impact on participants' responses in the IMI. In view of that, it is considered necessary to measure how participants perceived the G.E.L.'s usability with a customised version of the SUS to compare the results with the data collected with the IMI. The complete post-creation survey, including the IMI and SUS questionnaires filled by the participants, is attached in Appendix B.

6.4.2 Qualitative methods

Observational techniques

Semi-structured and unstructured observational techniques were conducted during the CHEM Jam's stage one. The semi-structured technique is inspired by Stables's framework (2008), which examined student learning activities in technology education.

The observational method aims to explore students' performance during the creation process. Qualitative tools to collect data about participants' behaviours can offer interesting results, especially if these results are compared with the participants' subjective answers collected by the quantitative methods, i.e. the IMI and SUS.

Stables original framework presented a pattern including precise actions defining different types of intentions and manifestations, as well as a dedicated space to describe particular observations and interventions, among other categories (Stables, 2008, p. 142). In line with the needs of the present investigation, the technique has been simplified to a semi-structured framework comprising two main categories: *manifestations*, what participants do during the creation process, and *interventions*, if assistance from facilitators was required and, in that case, what type of assistance. Unlike in the original framework, the categories, i.e. manifestations and interventions, did not indicate pre-established actions for each category. That is, observers did not have to choose from a limited list of manifestations or interventions and noted freely the actions observed in the two categories.

Observations on how specific manifestations were executed while creating levels, such as how teams organised themselves, and other kinds of observations that do not fall within the pre-established categories and were considered relevant to this study have been added to a separate table (table 5) that includes data observed randomly.

Additional data observed during the oral exam, in relation, for instance, to participants' comments on the CHEM Jam, have also been included in the previously mentioned table for analytical purposes.

6.5 Results

6.5.1 IMI and SUS

The two constructs measured with the IMI, interest/enjoyment and value/usefulness, comprised 7-point Likert-type scale questionnaires. Fourteen participants submitted the interest/enjoyment questionnaire, and twelve of them submitted the value/usefulness one.

The overall values of each participant and the means in both constructs are shown in fig. 39 and fig. 40 respectively.

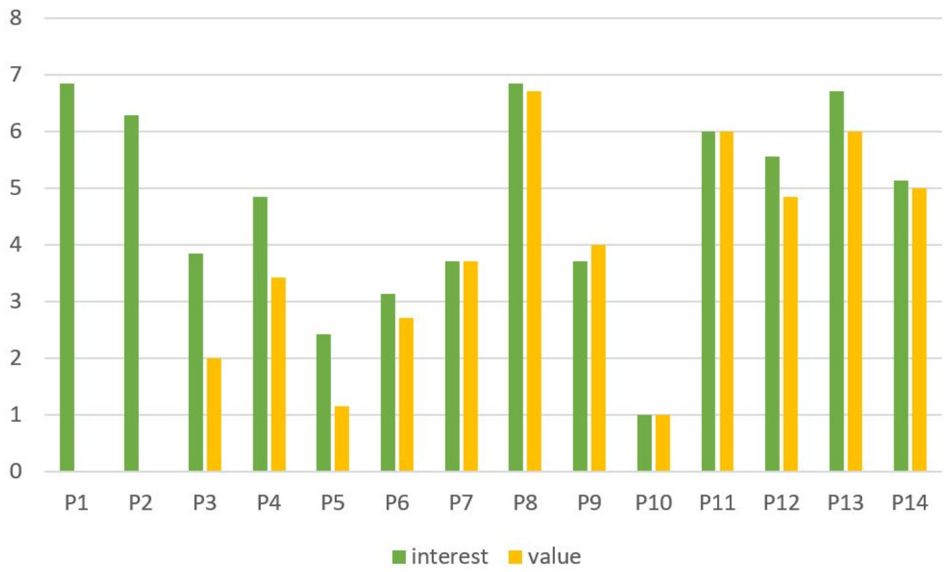


Fig. 39: Values of the responses of each one of the participants who completed the interest/enjoyment and value/usefulness constructs of the IMI.

Two participants (P1 and P2) completed only the interest/enjoyment construct. Both of them scored over 6 points out of 7 in intrinsic motivation.

The remaining twelve participants completed the two IMI's constructs. In most of the cases, except P7, P9, P10, and P11, the intrinsic motivation value of one participant ranked higher than the value/usefulness of the same participant. P7, P10, and P11 scored exactly the same value in both constructs and only P9 showed a higher score in value/usefulness than in interest/enjoyment.

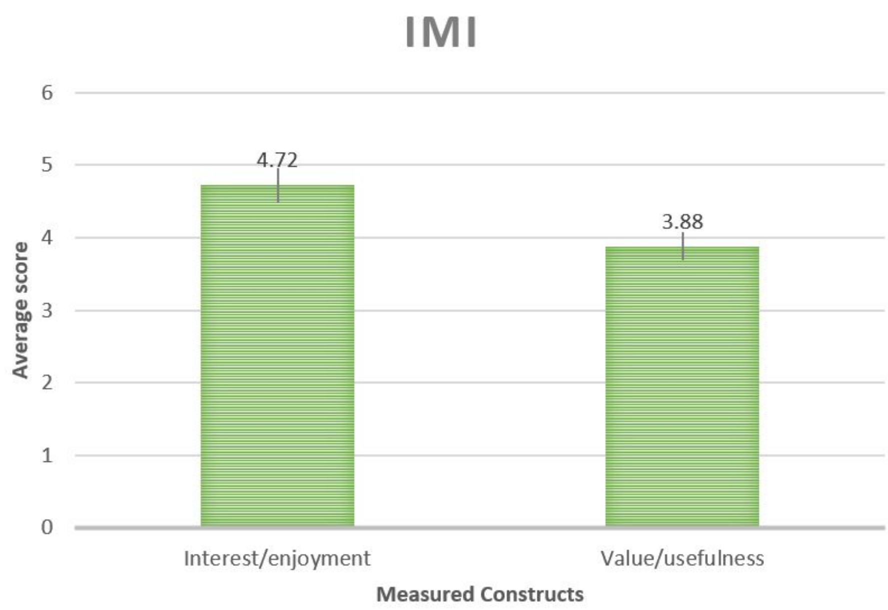


Fig. 40: Mean of the two constructs measured with the IMI.

Figure 39 shows the mean of interest/enjoyment, 4.72, and value/usefulness, 3.88, both constructs calculated on a scale of 7. The value of the first construct's standard deviation (SD) was 0.47. In the case of the second construct, the SD value was 0.34.

Regarding the SUS, twelve participants submitted the questionnaire, which was based on a 5-point Likert-like scale. The mean value was 65.83 out of a maximum of 100, which is graded as "marginally high" as per Brooke's scale (Brooke, 2013, p. 36).

6.5.2 Semi-structured observations

The data collected with the semi-structured technique during the level creation is displayed in table 4.

Group number	Team members	Manifestations	Interventions (time)
1	3	1. Planning work strategy 2. Discussing	Support for the editor (10:50)
2	2	1. Download G.E.L./ reading the tutorial 2. Drawing on paper 3. Discussing 4. Testing created level	Support for the editor (10:45, 10:50, 11:00)
4	3	1. Drawing on paper 2. Planning work strategy 3. Discussing	Bug in editor (11:15; 11:28)
8	3	1. Planning work strategy 2. Discussing	Level is done (13:00)
9	4	1. Planning work strategy 2. Reflecting on 3. Discussing	Bug in editor (11:00)
10	1	1. Downloaded G.E.L./ testing features 2. Reflecting on	Support for the editor (10:45)
12	4	1. Testing G.E.L. features 2. Planning work strategy 3. Discussing	Direction (12:49)
15	2	1. Drawing on paper 2. Planning work strategy 3. Discussing	1. Support and direction (10:45) 2. Bug in editor (11:15)

Table 4: Data collected with the semi-structured observational technique inspired by Stables's study (2009).

Table 4 shows the groups that participated in the CHEM Jam's creation process organised by number. The *group number* corresponds to the number they have assigned in the course, and *team members* indicates the number of members of each group that attended the stage one.

Groups 1, 8, and 9 started planning their work strategy. Group 9 also manifested some time of individual reflection on their computers after their work plan. Groups 4, 12, and 15 planned their work after manifesting another behaviour.

Groups 2, 10, and 12 started downloading the G.E.L. and/or getting acquainted with the main features of the editor. Also group 2, together with groups number 4 and 15, drew a paper draft of the level before using the G.E.L.

All the groups shared and discussed ideas about the game levels with other group members at some point in the creation process, except for group 10. Only one member of this group participated in the CHEM Jam, so he manifested reflection on the level he was creating instead of discussion.

Some participants requested support for using the editor, principally during the initial part of the creation process. Two other participants asked for directional interventions, that is they needed additional guidance on how to complete the level. Bugs were reported on three occasions and one team requested an intervention to announce that they had completed the level.

Finally, groups 3, 5, 7, and 13 did not attend the creation process which is why they have not been included in table 4. Groups number 11 and 14 are not mentioned in the table because these group numbers were nonexistent in the course.

6.5.3 Unstructured observations

The relevant information observed during the creation process and the oral exam is presented in table 5.

Group number	Total members	Creation process	Oral exam
1	4		1. Level presented improved a posteriori 2. Presentation theme: cartoons
2	4		1. Coins related to economy 2. Images copied from the PFD 3. They felt creation process was too short
3	3	NA	Interested but didn't have time to create a game level
5	4	NA	Didn't have time to create a game level
7	4	NA	Could not participate in the CHEM Jam due to family matters/tight schedule
8	5		1. Avatar status integrated in the process design 2. Found some bugs were inconvenient 3. Used exactly the same images than in the level example
9	4	Worked individually and chose the best of the 4 creations	1. Level presented won the CHEM Jam 2. Appreciated the editor's features for non-game designers to create games
10	4	Worked individually as only one member attended the creation stage	1. Creative game level, integrated in the end of the presentation as a summary of the process design 2. Long presentation including many process design details
12	5	Created a level that only represented the pre-treatment phase	1. Coins added in the most difficult gameplay path 2. Members attended in person but presented a video presentation 3. Bad quality sound in the video 4. Presentation file submitted online within the deadline's last minute
13	3	NA	1. Presented a brief game level of roughly 20 seconds 2. Most of the images used are the ones shown in the level example
15	4	Did not know how to represent a level because they usually do not have so much agency over their learning activities during the course	1. Presented a detailed game level 2. Seem satisfied with their creation 3. Long and precise presentation

Table 5: Unstructured observations per team during the level creation and the oral exam.

The *Group number* column in table 5 indicates all the existing groups in the course and, the column next to it shows how many members each group was comprised.

Group 1 presented a level in the oral exam that had been improved after the creation process time allocated for the event, that is the CHEM Jam's stage one. Their presentation had a cartoon-like theme that seem to correlate with the overall game level's style, as well as traditional 2D platformers.

The level presented by group 2 included coin items that were directly connected to the economical factors of the process design. Their level had the particularity that all the pictures used for the new game items were images directly copied from the icons typically used in PFDs (Process Flow Diagrams) as shown in fig. 41.

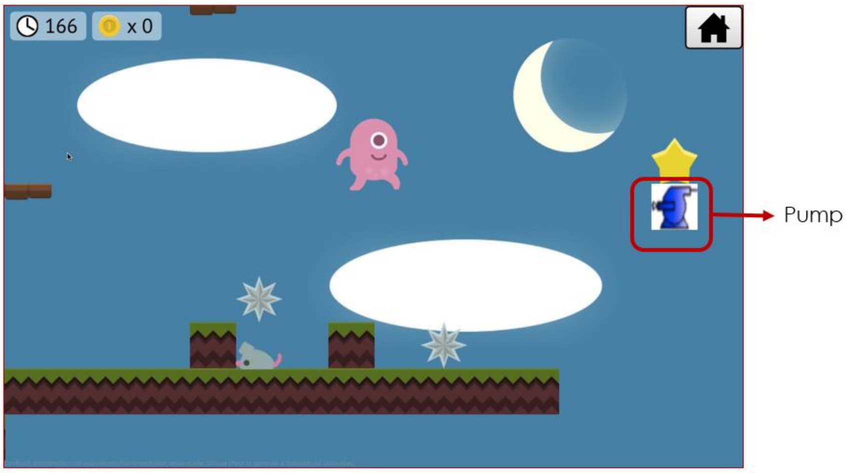


Fig. 41: Screenshot of the level created by group 2 in which all the new game items were created with icons typically used to represent elements of the PFDs, like the pump marked in red.

Groups 3, 5, and 7 mentioned that they did not have time to participate in the CHEM Jam event. Group 3 added that the activity seemed interesting, and one member of group 7 specified that she was not available during the weekends because of family obligations.

Both groups 8 and 9 added the avatar change of status in the process design to indicate that the product in the engineering process suffered a change (3.5.2 of this investigation). During the oral exam, group 8 pointed out that some bugs in the G.E.L. slowed down their level creation. The images used by this group to create new game items were identical to the images used in the new game items represented in the level example.

During the creation process, each member of group 9 made a game level individually. Next, the members chose the best level and presented it in the oral exam. A different approach to creating the level was also observed in group 10. Only one member attended the CHEM Jam, who created on his own the level that was later included in the oral exam's presentation of the group.

Group 12 created a game level that only represented the pre-treatment phase of their process design. Team members did not understand that game levels should represent the whole process design. When the group was advised about the missing content in their game level, the creation process time assigned to the teams, i.e. the stage one, was nearly over, so the group completed the level another day.

Group 13 did not attend the creation stage, but, in the oral exam, the group included a brief gameplay video of a level. The group made that level on their own and they mainly used the same images that were shown in the level example.

Finally, it is relevant to mention that, initially, group 15 seemed confused about what they were asked to do and mentioned that they were not used to enjoying so much agency during their learning activities. Despite their concerns, the group eventually presented a relatively long gameplay video of their level, which included all the elements necessary for an efficient engineering process design quite accurately.

6.6 Discussion

The findings indicate that CHEM Jam's participants felt intrinsically motivated during the creation process, with a mean value of 4.72 of the IMI's interest/enjoyment construct. Participants perceived the experience as considerably valuable, with a value/usefulness construct's mean value of 3.88, a rate lower than the previous construct's mean, but above the average threshold. In addition to that, the usability survey indicated a marginally high score of 65.83. The overall results of the IMI and SUS questionnaires together with the high participation rate, with members of 9 out of the 12 groups as per the participation in the oral presentation, suggest participants' significantly positive perception of the activity.

Generally, from the twelve participants that answer the two IMI constructs, the score in interest/enjoyment was accompanied by a score within a similar range in value/usefulness (figure 39), for which it is assumed that the two constructs are interconnected. That is, if the CHEM Jam's perceived value increases, participants will normally feel more motivated intrinsically than if the CHEM Jam's perceived value remains unaltered.

The introductory stage conducted at DTU did not contain thorough details about learning processes or outcomes because it was assumed that presenting the assessment methodology would provide that information. However, making games for learning in chemical engineering education is not a common practice, and few CHEM Jam's participants did not fully understand how they could attain the course's learning objectives with the event. This can be explained by the poor scores in value/usefulness of P10, P5, or P3.

During the CHEM Jam's introductory stage, a particular explanation about how learning occurs when creating levels, i.e. mainly by coping with challenges, could have improved the learning experience. It may help participants assume challenge is part of the learning experience, which would facilitate hints on what should be done to achieve the learning objectives. Overall, participants will make efforts to tackle problems, and learn from them, and, consequently, their perceived value of the activity may increase.

Due to the mentioned lack of details about the learning experience, some challenges were perceived as errors that required fixing rather than opportunities for learning. Table 4 shows that participants used interventions to report bugs in the editor on several occasions. While the reported bugs were unintentional, the errors entailed minor issues that did not impede participants from making levels and conveying the desired message. For instance, a bug was transforming pre-made coin items into pre-made mushroom items after saving and re-launching a created level. Participants could work around this specific bug by creating a new game item with a coin image, to which the properties of a coin item could be assigned.

It is assumed that the G.E.L.'s usability was perceived more negatively than expected if participants were aware that challenges and learning are closely interconnected. Besides the effects of minor bugs on usability, as pointed out by group 8 (table 5), using platform game editors in engineering processes is a difficult task that can be perceived as a usability problem. If participants ignore that the difficulties to align platform games with chemical engineering are intended, they will normally prefer a tool that fits better the learning content or, in other words, a tool that is easier to use, that is, with better usability than the G.E.L. However, in the present study, a more fitting tool would not comply with the degree of difficulty necessary for the activity. Finally, participants' better understanding of the CHEM Jam's learning approach will not only increase usability and value/usefulness scores in the surveys but also participants' intrinsic motivation.

When observing participants' manifestations in table 4, some behaviours clearly describe social interaction. Part of the interactions took the form of discussions before starting the creation process to establish a common work strategy among the different team members. On occasions, discussions were illustrated with a draft level drawn on paper, e.g. groups 2, 4, and 15.

Group 10 was the only team that did not show any social interaction, as only one member was present in the stage one. The participant showed different dynamics than the other team, principally based on individual reflection. The resulting level (see Appendix C), which was completed after stage one had ended, was clearly organised and the process flow could be easily understood. However, the participant failed to include all the unit operations. Even if the overall level was assessed positively, it is hypothesised that grades would be higher if group 10 had benefited from interactions and cooperative efforts.

The CHEM Jam event offers a game creation experience during which participants make levels with the G.E.L. This is a task that can be done intuitively, without needing programming skills or other specialised knowledge in game development. Consequently, fulfilling the task does not necessarily require cooperative work. A student can create a level individually, as exemplified by group 10. Group 9 is another example that levels during the CHEM Jam can be created individually. Each member in group 9 created their own level and, subsequently, the group presented what they considered the best creation.

The majority of the levels created by the groups that participated in stage one received higher scores than the level presented by group 13, who did not attend the game creation event. A possible explanation is that group 13 could not benefit from the positive implications of stage one in terms of motivation and teamwork. Group 13 may have decided to present a game level in the oral exam moved by the announcement that participating in the CHEM Jam could be regarded positively in the final grade. In this case, group 13 would be a clear example of a team motivated predominantly extrinsically, i.e. creating a level to improve their final grade. As the scoring demonstrates, extrinsic motivation is not a convenient approach in an educational context.

The experience of group 15 in the CHEM Jam is a relevant case of analysis for this investigation. The stage one attendants of group 15 showed initial skepticism about the experimental activity because their learning methodology in the course was normally the opposite of the CHEM Jam, which did not give them room for experimenting. During the level creation, the members of this group showed confusion about the activity's approach and asked for initial directions, i.e. clarifications on how they could start making a level.

Eventually, the group presented one of the most creative levels of the event, which can suggest that the CHEM Jam encourages novel thinking through a different learning approach.

6.6.1 Limitations, suggestions and future research

The observational technique has proved to offer useful insight with which suggestions for improvement and future research can be drawn. To corroborate the conclusions of the present study, further research should be conducted, which should be principally focused on the effects of collaborative learning. It is recommended to conduct a comparative study in which control and experimental groups can be structured. In the case that an observational technique is conducted to obtain the data, each observer should control two to four teams maximum to ensure that relevant data is not missed.

Some modifications in the G.E.L. can be considered, particularly to incorporate cooperative features. For instance, teams would find it easier to work collaboratively if there was a sharing feature in the editor, through which the same level could be accessible and changed from different computers simultaneously. The fact that some participants drew a draft level on paper indicates that the possibility to draw low-fidelity mock-ups in the editor, similar to the options offered by prototyping tools, would be beneficial too.

The CHEM Jam could include rules to represent industrial equipment for unit operations, or parts of it, in the levels realistically. That would add learning value to the image search and representation during the level creation. In addition, this change could encourage cooperation among participants, as well as avoid participants from copying the images offered as examples or from their PFDs. During the introductory stage, it should be explained that example images are not to be re-used in their creations if participants aim to obtain the maximum score in the creativity category.

None of the participants had the idea of creating new game items to genuinely represent the sustainability, economic, ethical, or environmental aspects of the design. Possibly, participants did not come out with representing the optimisation elements through new images in the new game items because the elements were not represented in the level example. This means that participants did not explore the editor's possibilities as expected. To encourage an exploratory and experimental attitude, the introductory stage of future CHEM Jams may be illustrated with a variety of level examples, as well as indicate that the four optimisation elements must be represented in the level to score a 3 in that category.

The event did not comply with some major elements that are characteristic of game jams. For instance, an important element is that game jams are typically events organised on two or three consecutive days to recreate an accelerated design process that favors creativity (Olesen, 2017). Since the CHEM Jam was structured non-consecutively, some participants finished the levels another day, even if the stage one was already over. The lack of experimentation of most of the created levels may be an indicator that time restriction is a relevant element of the experience and should be maintained, even if organising a time-restricted event of this reach in curriculum-based education may pose difficulties.

6.7 Conclusion

A CHEM Jam event was aligned with an undergraduate process design course at DTU in Autumn 2021. The study, organised over four non-consecutive days, aimed to explore the motivational, social, and other effects of the CHEM Jam.

A mixed methodology was applied comprising quantitative, i.e. the pre-validated IMI and SUS questionnaires, and qualitative methods, i.e. semi-structured and unstructured observational techniques. The results evidence that CHEM Jam's participants were intrinsically motivated and perceived the activity as considerably valuable. The G.E.L.'s usability scored "marginally high", which can be improved in a future intervention if more details about the learning experience are explained, i.e. that learning occurs by coping with challenges.

The results suggest that participants benefited from social interactions, which is why further comparative studies, including control and experimental groups, are recommended to corroborate the findings. Other observations, limitations, and suggestions for improvements are considered in the last part of the chapter.

Chapter 7

DISCUSSION

When it comes to making games for learning, some findings in this study suggest that limiting the activity to creating game levels, instead of a whole game, can offer an experience that is more apt to formal education than regular game jams or other activities involving creating games. One of the main reasons is that making game levels maintains the exploratory experience within the limitations of a specific game genre and, hence, can be completed in a reasonable time that fits the tight schedules of curriculum-based education.

It is observed that, while several overarching frameworks in game-making for learning have been studied, there is little focus on using specifically game level design in higher education, as well as how the created artifacts could align with curriculum-based education in STEM disciplines beyond subjects related to software or digital fabrication, game development or game design (Arnab et al., 2012, pp. 166-167; Weitze, 2021).

To facilitate game-jam-inspired events based on designing game levels for learning in STEM, referred to as game level jams hereafter, this investigation presents the conceptual framework named GaLeJam. The GaLeJam model indicates the principal steps to consider to integrate such events into higher education. The framework, based on key factors that have proved to be essential throughout the course of the present investigation, aims to answer the research question of the present investigation: *how students in chemical engineering education can benefit from making games*, and the subquestions introduced in chapter 1:

1. what learning approach can facilitate that learners make games for learning,
2. which tools are necessary to facilitate game making as a learning practice for chemical engineering students,
3. how can learning be measured during a game creation activity,
4. how can game making as a learning practice be integrated into curriculum-based education,
5. what are the implications of conducting the CHEM Jam in an undergraduate process design course of chemical engineering.

Even if the before-mentioned questions and sub-questions have been addressed throughout precedent chapters in this investigation, this chapter approaches them from a broader scope, discussing and reflecting upon the findings in the three empirical studies.

7.1 Conceptual framework

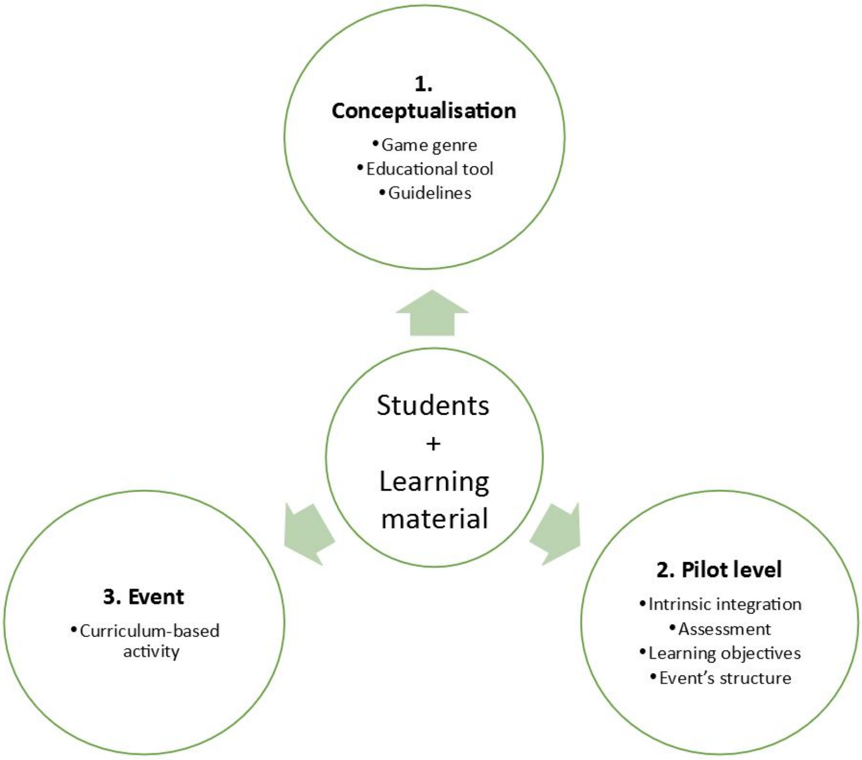


Fig. 42: The conceptual framework GaLeJam indicates the principal steps necessary to organise a game level jam for learning STEM in higher education.

A design-based research is proposed based on a constructivist pedagogy that can be conducted by researchers or facilitators willing to organise a game creation event in formal education. The approach situates target students and learning material at the center of the investigation. Students' degree of familiarity with programming languages is crucial to determine which type of level editor is more adequate for the activity, e.g. modding or authoring tools. The present study focused on learning exclusively chemical engineering material with a visual editing tool but other learning objectives and tools can be applied in the GaLeJam model.

7.1.1 Conceptualisation

One of the main duties of game level jam's facilitators is to offer an experience in which, among other things, a specific game genre has been associated with the learning material. To validate assumptions drawn on game genres that could facilitate the practice of the learning material when making a level, a conceptual study should be conducted (step 1 in figure 42). The conceptualisation step aims to validate the chosen game genre, gather data about the core features of the educational tool, and establish the essential guidelines of the event.

The educational tool can be an existing artifact, a custom-made prototype of an existing artifact, like the G.E.L., or a completely new functional prototype inspired by existing tools. Time should be allocated to modify or develop from scratch the educational tool.

7.1.2 Pilot level

Informed by the results of the previous study, the second step in the GaLeJam model aims to test the chosen educational tool and analyse one or more levels created with the tool by targeted students. The pilot level(s) should shed light on the intrinsic integration of the learning material with the game mechanics. Focusing on the intrinsic integration of educational games helps to "dismember" the game and see details on connections/relationships between content and game mechanics.

The detailed information found about the pilot level(s) can be used to draw a pattern that can be associated with existing assessment frameworks and find inspiration for an effective assessment methodology to be used in this study. For example, during the pilot study of this investigation, the pattern helped to understand how flowcharts function in platform games and associate them with concept maps for the assessment (5.7).

To preserve the game flow of a level during a level making for learning approach, which would favor intrinsic integration as addressed in 5.6, it is argued that the level must reproduce existing game designs that are balanced and have proved to be successful, i.e. games with a minimum of popular appeal. In other words, the educational tools should facilitate the creation of levels with core game mechanics typically used in existing, mainstream games so that the levels created can maintain the game flow. For this reason, the tool presented in this investigation, i.e. the G.E.L., is inspired by platform game editors, a popularly acclaimed commercial game genre (4.2.1).

The GaLeJam model encourages an exploratory, design-based approach to finding off-the-shelf, commercial games compatible with the designated learning material. Students in STEM disciplines, other than software/game development or game design subjects, do not usually design games for learning. The new practice may bring novel, different perspectives to the field of serious games. Some outcomes of such a practice are exemplified by the integration of the G.E.L., an editor based on an action game that can have been effectively associated with chemical engineering content. The editor offers a 2D, cartoon-style appearance that showed significantly positive results during the intervention at DTU despite not being a conventional educational tool employed for learning engineering material.

A relevant part of this investigation is to propose a bottom-up approach in which a successful assessment is created from the lens of a resulting level (chapter 5 in this investigation). A substantial part of participants' understanding is reflected in the levels, which is why the levels are considered the foundation on which the assessment should be based. Besides assessing, the assessment methodology is relevant to two other key factors of the GaLeJam model: the guidelines and the learning outcomes.

The new assessment methodology is used as guidelines during the introductory stage so that participants know how the levels will be assessed at a later stage. That is, the intended learning outcomes are presented with each one of the methodology's scoring criteria. Additionally, the team with the higher score will be selected as the winner of the GaLeJam, which means that participants will have to follow the pre-established criteria if they want to win.

7.1.3 Curriculum-based intervention

Starting with the learning objectives and time frame, the last step of the GaLeJam model aims to define the structure of the event. The learning outcomes of the course, into which the event should be integrated, are aligned with the assessment criteria produced from the previous study.

Ideally, the event should be organised on 2-3 consecutive days to replicate a learning experience as similar to game jam events as possible. Due to time constraints in the process design course at DTU, offering an event organised on various consecutive days was not possible. However, preserving the conventional, accelerated event's time frame will have a positive impact on the learning experience since creative processes benefit to a great extent from constraints that place creators in time-restricted situations in which their full attention is crucial (Olesen, 2017).

To ease the alignment within a curriculum-based course, it is crucial that the resulting artifacts have a meaningful function in the course program. For instance, the levels resulting from the CHEM Jam were used as a communication channel. Through the created levels, the groups communicated their engineering processes designed along the process design course during the oral exam. Students were encouraged to include the levels in their presentations, even though the CHEM Jam was a voluntary activity.

7.2 Implications

Considering the results obtained throughout the empirical work for this investigation, this section aims to address the general implications of a GaLeJam event, mainly from a cognitive, motivational, and social perspective.

7.2.1 Cognitive effects

It has been argued that a game creation event can be presented as a unique activity to foster creativity and critical thinking through the transfer of knowledge, that is to reinforce content previously taught and explore new applications or directions (5.2).

Particularly in the case of a game level jam, the event does not require so much research and technical skills as making a game from scratch and so learning can be easily directed to the learning outcomes of a particular course.

The introductory stage in study three did not put too much emphasis on game level design and learning content integration because the investigation was still in its infancy. Previously in this chapter, it has been argued that promoting intrinsically integrated levels during the pilot study can benefit the analysis of the level content-wise. If intrinsically integrated levels are to be encouraged during game level jams for learning, the events should incorporate a game level design workshop. For instance, the workshop during a CHEM Jam would provide recommendations to create balanced platform game levels.

A balanced game design when referring to platformers has to do with rhythm because of the nature of this game genre (Compton and Mateas, 2006, p. 109). Balanced platform levels provide an enjoyable playing experience that follows game flow theory, i.e. the levels are neither too simple nor too complicated, which means that a balance between the skills of the player and the challenge of the game is maintained (Csikszentmihalyi, 1990; Holt, 2000; Chen, 2007).

The suggested pattern to achieve balanced platform games in this investigation comprises three principal elements. The first element to consider is the action point in a platformer. The game needs the player to take action, normally requiring the player's full concentration in order to progress in the game. Another relevant element of platformers is a resting point, during which players can pause, think, and plan their next moves. Finally, a balanced platform level needs exploration points too, so that players are allowed to explore their surroundings and are posed with puzzles to solve. Along with the inclusion of these three types of elements is the need for logical flow so players experience a smooth play experience.

Providing a table with the game items and their interactions in the game, similar to the table for the G.E.L. (3.2 in this investigation), helps participants to have an overview of the available resources to make the levels and may help to create correlations with the learning material for their intrinsic integration in the game.

Specifically, to promote intrinsically integrated game levels during a CHEM Jam, a guide can be proposed. For instance, each action, resting, and exploration point in the levels could correspond to specific unit operations in an engineering process design. In fact, a balanced game design can be encouraged with a new scoring category for game design. This new category is more specific and can replace the creativity criterion suggested in chapter 3, which is quite abstract and can easily lead to confusion.

In sum, making intrinsically integrated game levels seems a feasible technique that could shed light on how the learning material can be integrated into the game mechanics for participants. That is, intrinsically integrated levels may have a positive impact in terms of guidelines and structure of the game level jam. However, extending guidelines and adding information about how game levels should be structured does not benefit a learning strategy that is propelled by learners' exploration. In other words, it is clear that playing educational games in which the learning content is integrated intrinsically has the advantage that learning is discovered through the core mechanics of the game. However, in a learning experience based on game making, the notions of intrinsic integration, game flow, and balanced game design do not seem to favor learners cognitively, but rather diminish the exploratory options, and, therefore, the opportunities to learn.

Here it is argued that learning can most likely occur in an experience based on learners making games or game levels that do not comply with the game design norms, game flow theory, and/or the intrinsic integrated notion. However, it would probably be difficult to drive the activity towards some pre-established learning outcomes and, hence, to include the experience in formal education.

Comparison with estimated grades

To analyse some cognitive effects of the levels created during the intervention at DTU, the scores given to the levels, available in appendix A, are compared to the estimated grades of the oral exam (table 6a).

Group	Oral exam	Game level
1	7-10	10
2	7	6
3	10-12	--
4	7	4
5	12	--
7	12	--
8	7-10	3
9	10-12	10
10	12	10
12	4	3
13	7	4
15	12	5

Danish mark	Explanation of the mark	Equivalent ECTS mark
12	For an excellent performance	A
10	For a very good performance	B
7	For a good performance	C
4	For a fair performance	D
02	For an adequate performance	E
00	For an inadequate performance	Fx
-3	For an unacceptable performance	F

Tables 6a and 6b: On the left, table 6a with the estimated grades for the oral exam and levels' scores of all the groups who attended the process design course at DTU in fall 2021. On the right, table 6b shows the Danish 7-point grading scale and the ECTS mark equivalents. (*Table 6b courtesy of Danish Ministry of Children and Education website*).

The estimated grades of the oral exam are based on the Danish 7-point grading scale (table 6b) which ranges from a 12 mark for excellent performance to a -3 in case of unacceptable performance. For the levels, the improved scoring system, i.e. comprising four categories and a maximum score of 12 points (3.5.1), was applied.

An indication that the improved assessment methodology is applicable to game levels of a process design course is that, overall, grades in the oral exam and the game levels coincide. In other words, groups with an over-average or below-average estimate grade in the oral exam scored similarly in the game level, e.g. groups 1, 9, and 10 received over-average estimates and scores whereas group 12 under-performed in both activities.

However, groups 8 and 15 did not score as high as their estimated grades. In the case of group 8, this could be explained because the learning approach was misunderstood. Some challenges were not perceived as opportunities to learn but as bugs of the editor, which was reflected in the missing learning content that the group presented.

Group 15 confessed that, even if they enjoyed the experience, they were not used to having so much agency over their learning and were confused about how to proceed. Some criteria in the assessment were missing, which could be explained because participants were presented with the assessment's original version. The original version, which was briefly explained during the intervention at DTU, comprised six criteria instead of four and may have led to some participants' confusion because some categories were not completely clear and/or easily aligned with the Process Flow Diagram. As a result, it is observed that most of the created levels were incomplete.

Groups 1, 9, 10, and 15 were the groups that benefited the most from the experience with the highest scores in the creativity category. The overall scores in this category were quite low, which may imply that encouraging creativity should be improved. The suggestions about including a game design workshop to promote the creation of balanced game levels could be adopted to give participants new ideas and increase the score of the category creativity. However, as mentioned before, this would come with detriment to learners' challenges and reflection.

7.2.2 Motivational effects

The results of study three have demonstrated that the CHEM Jam motivates participants intrinsically. It is argued that game jams offer a learning experience within a game, consisting of making a game, and through this playful approach, game jams provide plenty of opportunities to make participants feel competence, relatedness, and autonomy (Filak and Sheldon, 2003; Monteiro et al., 2015, p. 435; Grey et al., 2018) which is why participants are engaged intrinsically.

In chapter 6, it has been argued that extrinsic motivators can diminish intrinsic motivation, which overall has a negative impact on creativity. The level created by group 13 is possibly an example of an extrinsically motivated creation. The team did not participate in the CHEM Jam event but they presented a level along the oral exam, which was done in isolation on their own. It is likely that the motivation behind doing that level was getting a higher grade, an extrinsic motivator since it was announced that the levels would be regarded positively for the evaluation of the process design course. Together with another group, group 13's level received the lowest total score, 4 points, which suggests that extrinsic motivators are not positive for learning.

Another type of extrinsic motivators that are not usually recommended for learning are competitive activities in which a winner is designated. Nevertheless, here it is argued that the competitive aspects of the CHEM Jam remain undermined by the playful approach of the events. That is since game jams are essentially games, the competitive aspects do not motivate jammers extrinsically. Instead, jammers main motivation remains mainly learning and having fun.

Finally, it is possible that the notion of intrinsic integration, despite the unwilling impact on the exploratory factors of game level jams, may direct participants' attention principally towards the learning outcomes. That is, participants must focus on the learning content to explore how to best combine the content and the message to convey with the available interactions. Therefore, it is assumed that this practice would most likely benefit participants' intrinsic motivation.

7.2.3 Social effects

As addressed in section 6.2, collaborative learning can reinforce learning with social interactions that complement individual reflections. Additionally, collaborative learning introduces cooperative efforts that do not involve others' failure (Deutsch, 1962; Johnson and Johnson, 1989). Game jam events include some competitive aspects since a winner is normally selected and there can be a winning prize. In the previous subsection, it was mentioned that game jams do not motivate participants externally despite the competitive aspects. However, there is another reason why well-executed game jams should be part of formal education.

The main reason is related to the type of competition encouraged during game jam events. Within the teams, social interdependence occurs because common goals are shared and each one's success depends on other's actions. Besides that, it is argued that the competition in game jams remains moderate and does not trigger a negative effect on participants, such as motivating them externally, because selecting a winning team does not involve the other teams' failure.

It is important to observe the working dynamics of teams that received the top scores in the levels presented during the intervention at DTU. Groups 1, 9, and 10 scored 10 points out of 12 with their levels, which was the maximum score in the event (table 6a). Of the three winning teams, only group 1 created the level as advised, that is the four team members participated in the game creation activity and created one level on a shared computer.

The four members of group 9 decided to create one level each and compare the creations to vote for the level they wanted to present. It is assumed that the group did not directly discuss creation decisions such as the representation of each new image or how to apply the limited interactions to benefit the representations. However, it is argued that the team benefited from creating a competition within a competition that would have not been possible if the members were not motivated by shared goals.

The level presented by group 10 was created individually by one team member. Despite the individualistic approach, the level received one of the highest scores and was particularly creative compared with all the other levels. This can suggest that creative processes may benefit from individual inspiration and ideas that do not have to meet the common consensus of collaborative learning. By working with other members, creations are less creative because people tend to be more cautious and filter their thoughts.

The space in which the activity is conducted plays a relevant role in the learning process. In the case of game jams for formal education, providing an open, informal setting situated out of the regular space in which the course usually takes place is an important factor. The informal setting is more adequate to offer participants a community-like environment constructed to assist learners, one of the principles in the Maker Movement manifesto (Hatch, 2014). In fact, the GaLeJam model facilitates a conceptual framework through which six essential elements to create a community-like environment in education (McKinney et al., 2006) can be achieved: connection, participation, safety, support, belonging, and empowerment.

7.2.4 Other

The GaLeJam model is targeted at young adults to learn by co-creating at a higher education level. The activity requires a certain abstraction and maturity level that younger learners may have too much difficulty achieving. Considering the positive findings of study two, it is recommended to test this learning approach with graduate students. Graduate students may approach challenges more confidently than undergraduate students, and studying their creations may provide interesting insights.

An additional aspect of the GaLeJam model that makes the activity more suitable for higher education is the experimental approach. That is the model encourages educational specialists designing the learning concept to follow a design-based approach and find effective unconventional tools or interactive items that have been rarely matched with specific learning content. The experience may even offer an activity in which the intrinsic integration of game design with learning material is not really feasible. It is assumed that learning and co-create in such an unconventional environment require a high level of understanding that can create frustration instead of motivation in infants or pupils.

Finally, it is important to mention that maker-centered activities, when introduced in curriculum-based programs, can help to promote diversity and equity. For instance, Lorenzo and Lorenzo's study (2019) presents a maker-centred educational approach that could contribute to the inclusion of young people in vulnerable social environments, as well as students with disabilities and learning difficulties in Higher Education. More precisely, the work of Villanueva Alarcón et al. (2021) investigates how equitable access is enacted in making spaces for chemical engineering.

7.3 Limitations

One limitation of the GaLeJam model, and employing level design instead of game design in particular, is that educational specialists, learning designers, and any teacher or facilitator interested in applying the model must anticipate a considerable amount of time before conceiving an effective, integrated experience, i.e. for the conceptualisation of the activity, especially the educational tool, as well as the pilot study. In addition, educational experts do not necessarily possess programming skills and may encounter difficulties developing a custom-made tool, or finding collaborators for that matter.

Learning was measured through the lens of the created artifacts in which the creators' understanding is reflected. The practice has shown to be effective to frame the experience to the intended learning outcomes, as well as providing constructive feedback to creators. Nevertheless, this study does not show explicitly the positive effects of the CHEM Jam in the course compared to a course without a CHEM Jam. A possible comparative study could involve measuring participants' prior knowledge about process design before the CHEM Jam so that results can be compared to participants' knowledge after having completed the activity.

To explore how learning occurs during the creation process, the social effects, that is how participants interact with each other, were analysed by conducting structured and unstructured observational techniques. This technique facilitates information about participants' manifestations, which is valuable information for the present investigation. However, finding a method to measure specifically the cognitive effects of working collaboratively, instead of behaviours during the creation process, could have extended the cognitive results of this study.

The second part of chapter 3 in this investigation explores the principal factors for educators and facilitators to consider when aligning a game creation event in formal education. However, the information is quite limited and further attention must be directed to the role of teachers and educators. The instructors' role is a key factor in game making for learning experiences (Weitze, 2021, p. 751). Due to time constraints, setting out from target students, the educational tool, and context to explore the proposed learning approach in this investigation were prioritised over the role of instructors.

7.4 Future perspectives

Overall, learning experiences involving making game levels may see the collaborative needs reduced. In other words, collaborative work is not a major requirement to make a game level, since the technical requirements and overall complexity of the activity are simplified when compared to making games from scratch. In any case, it is likely that making game levels individually imply a novel and effective approach to making games for learning.

Alternatively, to encourage collaborative learning, GaLeJam facilitators can design collaborative tasks embedded in the learning experience. For instance, educational tools could include features that facilitate making levels collaboratively, e.g. simultaneous screen sharing or a network storing and facilitating access to the created artifacts.

The implications of intrinsic integration in game level jams and how could game level jams facilitate appropriate guidance that does not jeopardise learning should be further explored.

It has been mentioned the possibility to apply the GaLeJam model or game level design in other STEM disciplines due to the special requirements to learn STEM subjects, i.e. theoretical knowledge needs to be transferred to a problem-based situation to ensure understanding. Existing research about serious games, especially systematic reviews about serious games in a particular field, can be used as inspiration to consider game genres for a game level jam. The similarities between game level design and architecture (Totten, 2014) suggest that the GaLeJam model may be extended beyond STEM to architectural studies and overall design disciplines.

Future research should consider the implications of the CHEM Jam in multidisciplinary teams. Students in higher education could profit from game making events to create educational games. The multidisciplinary game jams could be organised among, for example, future computer scientists, game designers, artists, and engineers.

This investigation advocates for a learning approach through which students make games without needing programming skills, which allows for keeping the learning material as the focus of the activity. However, the approach may be valuable for extending learning with programming skills. Finding an appropriate tool and game genre could be adopted in the learning process if the learning materials involve software/game development. There is the possibility of cross-disciplinary collaborations between students of programming/games and other disciplines.

Game jams can commonly introduce a surprise factor, which increases creativity because participants are obliged to improvise, by announcing a specific theme right before starting the creation process phase. For the GaLeJam framework, announcing a last-minute theme can be problematic because participants need to know the assessment criteria beforehand. Future research should further investigate how can game level jams offer a surprise factor that increases participants' creativity.

Overall, higher education should explore new learning approaches inspired by methodologies traditionally known as kindergarten-style practices. If more academic research is focused on this kind of learning approach in formal education, knowledge can be associated with a hands-on experience in higher education, which will contribute to effective, experimental ways of learning. For instance, Ejsing-Duun and Pischetola (2022) introduces a study with a group of undergraduate students in communications and media to learn by designing with LEGO bricks.

Chapter 8

CONCLUSION

Learner-centred pedagogies in which learners are given much agency over their experiences to learn by exploration and experimentation (Aubrey and Riley, 2016, p. 2-4), have recently drawn some academic attention (Kafai and Vasudevan, 2015; Roque et al., 2016; Paciarotti et al., 2021). Among its advocates, Mitchel Resnick defines this type of learning as a kindergarten style and argues that the approach is beneficial to and should be adopted by 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 the capacities necessary for a rapidly changing society like ours. Educators cannot give specific solutions to future problems but can facilitate an environment for learners to think critically and solve problems creatively.

Similarly, research in chemical engineering education (Varma and Grossmann, 2014, Udeozor et al., 2022, p. 1-2) posits that novel learning approaches should be considered, particularly those encouraging learners' problem-solving skills. To provide new, challenging practices in which learning is approached differently than in conventional teaching methodologies, this doctoral dissertation investigates a learning experience based on students making games for learning in chemical engineering. The experience is explored through design-based research focused principally on cognitive, motivational, and social effects.

8.1 Summary of the dissertation

The initial inspiration for the present investigation set out on constructionist theories and works, mainly led by Papert, and Resnick at a later stage, to extend teaching methodologies in STEM (Science, Technology, Engineering, and Mathematics) disciplines. In Piagetarian constructivist-based experiences, the baseline of Papert's work, infants construct their own learning, which normally occurs through reflection and experimentation (Piaget, 1954). This learner-centred approach introduces learners to challenging experiences to learn and reflect upon. That is, understanding is constructed actively when learners solve problems.

It is argued that Papert's constructionism reinforces Piaget's theory by introducing computers as educational tools in the learning process. In constructionist practices, learners do not only create knowledge but also an artifact, which favors sharing the creations, social interactions, and, hence, collaborative learning (Shaw, 1995; Kafai and Resnick, 1996, p. 4).

To conceive an educational context favorable to learning by making, this investigation is inspired by the Maker Movement, an extension of the DIY (Do-It-Yourself) cultural trend, and its common practices to gather in public spaces to tinker, e.g., electronics (Martin, 2015; Schad and Jones, 2020). The community in maker spaces is an influential pillar for the present investigation because makers can interact with each other to ask questions, share doubts and opinions, or observe other creations. These spaces present typically constructionist experiences that engage participants with the creation process by empowering them.

Several empirical studies have demonstrated that learning implying fabrication impacts positively in STEM. Some of these examples are Kafai et al.'s work (2014) on e-textiles creation and Burton et al.'s study (2018) that investigates a mission to Mars project through which students actualize mathematical principles in the production of a rocket.

Particularly game jams, hackathon-like events to create games in a relatively short period of time (Kultima, 2015a), have become a popular practice, especially among aspiring professionals of the game industry and game enthusiasts. Recent studies evidence the efficacy of these events for learning (Fowler et al., 2016; Meriläinen et al., 2020; Lai et al., 2021) and the motivating effects of making games on learners (Gee, 2005; Grey et al., 2018).

Previous studies on game jams for learning can be found in research specifically to develop computational thinking (Boulton et al., 2016), soft skills (Contreras-espinosa and Eguia-gómez, 2022), or in general formal education (Aurava et al., 2021). Most of the research in learning by making commonly applies to primary and secondary education (Jeffrey Earp, 2015; Weitze, 2021) and there is little evidence of game creation events applied specifically in engineering education (Lai et al., 2021).

Building on constructionist theories and cultural trends, i.e. game jams, the learning experience proposed in the present investigation is named CHEM Jam. During the CHEM Jam, participants use a custom-made Game Editor for Learning (G.E.L.) to design levels for a jump n' run/platform game. The editor, designed having particularly chemical engineering students in mind, facilitates the construction of games for non-game designers. Game items can be created by skinning 2D images and used on the levels through a drag-and-drop system.

The CHEM Jam event was aligned with a process design course, a mandatory course in the bachelor degree in chemical and biochemical engineering at the Danmarks Tekniske Universitet (DTU). Ideally, the CHEM Jam should be organised like game jams, on 2-3 consecutive days. However, mainly due to time constraints in the course and to align the experience with participants' knowledge, the event is eventually conducted on different, non-consecutive days.

The introductory stage of the CHEM Jam, which is structured in three stages, presents a workshop that explains the structure and assessment methodology of the activity to the participants. The assessment methodology evaluates mainly the learning content of the game levels to frame the CHEM Jam in the process design course. During the next stage, stage one, participants create game levels collaboratively with the G.E.L.

A key element to consider for the creation process is the space. It is argued that an informal, open space out of the conventional classroom will create a different environment to favor collaborative learning and creativity. In the last stage, participants present and share their creations. At the end of the last stage, the facilitator selects the winner of the CHEM Jam based on the assessment criteria that were introduced in the introductory stage.

The CHEM Jam is the outcome of this design-based investigation that comprises three empirical studies. Study one, involving the conceptual work, set outs on the hypothesis that platform game level editors can be used as educational tools for learning chemical engineering by making platform game levels. The study, conducted online in December 2020, aims to test the applicability of platformers with the learning material and explore what essential guidelines are needed to offer an effective learning experience.

Inspired by the participatory design technique, for study one, six participants, with a background in either chemistry or chemical engineering, tried to make chemistry-related game levels with the mobile application *Level Editor for Platformers* (Felgo, 2016). Chemists attempted to represent a chemical formula on a level, whereas chemical engineers worked on the industrial production of acid citric.

After analysing the results, two main hypotheses are drawn. The first hypothesis is that the editor, re-named Game Editor for Learning (G.E.L.), should incorporate a new feature through which new game items can be created. The feature will ease the integration of chemistry-related images in form of game items in the levels. The new items function as skinned versions of the editor's pre-made items, which means that how the new items interact in the game remains limited to the existing interactions. The limitations are constraints offered to participants that aim to maintain a certain degree of challenge in line with the students' needs.

The second hypothesis that can be drawn after analysing study one's results is that guidelines needed revision. Since two participants did not know how to approach the activity, it is argued that the activity fail to facilitate the necessary information for students who may not be familiar with or much used to playing videogames in their spare time.

The next study was conducted when the first prototype of the G.E.L. was completed to explore how the levels could be assessed. Study two was conducted online in February 2021 with two undergraduate students in chemical engineering from KU Leuven, Belgium. Participants created a pilot level with the G.E.L. that included physical and chemical phenomena, as well as industrial equipment typically used in engineering processes to produce ammonia.

After a qualitative thematic analysis of the pilot level, the pattern found helps to understand how flowcharts can be associated with process design in chemical engineering and efficiently assist students to initiate the creation process. From the similarities between concept maps and flowcharts, which are broadly used to create engineering process designs, an assessment methodology is produced to assess the game levels generated during the CHEM Jam.

Five colleagues of the CHARMING project assessed the pilot level with the tailored-made assessment methodology. The activity aims to verify the applicability of the methodology in chemistry-related platform levels. The positive results show that the assessment is an effective tool to measure the learning material in chemistry-related platform game levels.

The final part of study two addresses how the assessment methodology was used to assess the levels created for the CHEM Jam intervention at DTU. The scoring system not only provided constructive feedback to participants but also determined the winner of the CHEM Jam. Finally, an improved version of the assessment is considered. The assessment is subject to modifications for the empirical study in the present investigation to propose effective criteria that align the learning outcomes of the mandatory course in process design at DTU.

As part of study three, the CHEM Jam event was integrated into an undergraduate process design course at DTU in Autumn 2021. The study, organised over four non-consecutive days, aims to explore principally the motivational and social effects of the CHEM Jam. A mixed methodology was applied comprising quantitative, i.e. the pre-validated intrinsic motivation inventory (IMI) and system usability scale (SUS) questionnaires, and qualitative methods, that is semi-structured and unstructured observational techniques.

Study three's results show that CHEM Jam's participants were intrinsically motivated with a 4.72 mean value on a 7-point scale and perceived the activity as considerably valuable with a mean value of 3.88 on the same scale. The G.E.L.'s usability scored "marginally high", which can be improved in a future intervention if more details about the learning approach are explained to participants, i.e. that learning occurs by coping with challenges. The results of the IMI and SUS questionnaires together with the high participation rate, members of nine out of the twelve groups in the course created a level, suggest participants' overall significantly positive perception of the activity.

The results of the observational techniques show how participants planned their creation processes and suggest that participants may benefit from social interactions, even though the findings are not conclusive in this respect. To investigate further if social interactions can be beneficial for learning during the CHEM Jam, a comparative study, including control and experimental groups, is recommended. Other observations, limitations, and suggestions for improvements are considered in the last part of study three.

A conceptual framework is proposed based on the three empirical studies conducted for this investigation. The framework GaLeJam, Game Level Jam, summarises the three principal steps necessary to organise a game level jam for STEM in Higher Education: conceptualisation, pilot level, and event. The findings in the present investigation suggest that designing game levels instead of games may be more convenient for curriculum-based learning because the experience is constrained to producing levels, which can be easier to align with specific learning outcomes than producing a whole game.

The GaLeJam model situates students and learning material in the center of the framework. The conceptualisation step should consider which educational tool and essential guidelines can be adequate for the experience considering target participants and intended learning material. The educational tool and guidelines should be tested with target participants to inform whether crucial changes in the tool and guidelines are necessary. Next, a pilot level should be created, which will shed light on the intrinsic integration between learning material and core game mechanics.

The intrinsic integration in serious games, a concept coined by Habgood et al. (2005), refers to educational games that benefit from the flow of the game experience since the learning material is discovered through the core mechanics of the game. For the present investigation, which is based on learning by making games instead of playing them, the notion of intrinsic integration can be useful during a pilot study. As seen in chapter 5, a pilot level that shows intrinsically integrated content can help validate the guidelines of the learning approach, as well as find associations with existing studies to generate an efficient assessment methodology for the levels.

Promoting balanced game levels that offer a game flow, in line with the psychological theory of flow (Csikszentmihalyi, 1990), can favor the creation of intrinsically integrated game levels. Csikszentmihalyi's theory of flow (1990) argues that individuals can achieve a state of flow that involves joy, creativity, and involvement. The state of flow can be reached when someone is focused on realistic goals that match their skills. The same theory is applied in games: a balanced game will offer an experience that is neither too difficult nor too easy for players. Particularly in the case of platform games, in which rhythm is crucial, it is argued that designers must consider action, exploratory, and resting points to create balanced game levels.

Even if a balanced game design and intrinsic integration are key aspects of serious games and learning by playing, it is argued that these aspects may not have a crucial cognitive impact on, particularly, learning by making games. This investigation suggests that, since learning occurs during the creation process, it is likely that CHEM Jam's participants learn from making unbalanced game levels or levels that are not intrinsically integrated. Contrarily, if the integration of content is too evident, the learning experience will be ruined due to a lack of challenge. In other words, in a GaLeJam model, the challenges encountered during the creation process are essential for learning, whereas the resulting artifact and if it complies with the rules of effective game design and serious games are less important.

Drawing upon the last argument, this investigation argues that educational tools for the CHEM Jam can be inspired by existing, off-the-shelf game editors and engines that have not been created for learning specifically chemical engineering. The advantage of using commercial editors or tools is that the experience entails an adequate challenge through which students in higher education reflect, experiment, and learn. An additional upside of off-the-shelf digital tools for learning is that the tools help to align learning with popular culture and how young adults communicate, which can attract students into the learning experience.

The assessment methodology generated during the pilot level, the second step in the GaLeJam model, is used to frame the experience within the intended learning outcomes.

The assessment is introduced to participants before the creation process starts to clarify under which criteria the levels will be assessed and the winner of the event, selected. Finally, the assessment criteria, which are directly related to the learning outcomes of the experience, help to facilitate a learning experience with specific learning outcomes that can be aligned with a mandatory course in higher education.

The structure of the event, ideally comprising an introductory stage, stage one and two as the CHEM Jam, is paired with the time schedule of a mandatory course in higher education. Since a cognitive effect of the GaLeJam model is encouraging knowledge transfer, i.e. prior knowledge is effectively applied in a new context (Wittrock, 1974), it is argued that, for a more effective learning experience, stage one should be organised when participants have acquired the relevant prior knowledge. That is, in the case of the CHEM Jam at DTU, participants needed to know the fundamentals of their process designs prior to making the levels.

The results of study three show that participants were intrinsically motivated. It is argued that game jams are essentially games that consist of making a game, which would drive to motivate participants intrinsically, i.e. participants are motivated by the fun factor. In addition to that, the fact that the GaLeJam model focuses on levels benefits the intrinsic motivation of participants because participants' attention is directed to how the learning material can be integrated intrinsically into the level. From this perspective, balancing game levels may not have a cognitive effect on participants, but it does have a motivational one.

The observations during study three suggest that participants benefited from collaborative learning during the CHEM Jam. Even if further studies should be conducted in regard to how collaborative learning occurs during the CHEM Jam, the findings demonstrate that the competitive aspects introduced by the event do not have a negative impact on participants. One argument to explain the positive effects of presenting a competitive event such as the CHEM Jam is that the winner of the event does not imply others' failure. A second argument that would explain the positive competition is the playful approach. Since game jams are fundamentally games, competition is not the main aim of the events and can motivate participants intrinsically.

The findings in this investigation show that game level design for learning has an impact on core factors of the learning experience when compared to making a whole game for learning. Essentially, the experience becomes less technical when learners are making levels instead of games, which implies that collaborating with peers, and, consequently, learning through collaborative learning, is not a fundamental aspect to create a level. Future research should consider game level jams that do not necessarily promote collaborative creations. Creative processes may benefit from individual choices and reflections that do not need other peers' consensus or understanding.

Appendix A

CHEM Jam's scoring

This table indicates each group's scoring, divided by category, for their created levels during study three:

Team	Scoring				
	Organisation	***Unit Operations***	***Optimisation***	***Creativity***	***Total score***
Group 1	3. Well organised.	3. All unit operations represented.	2. Showed the entire overhead products recycling process but missed other optimisation elements.	2. Genuine pictures but interactions are not used creatively.	10
Group 2	2. Did not follow the process flow diagram accordingly. There was no mixer at the beginning of the game like in the process flow diagram.	2. Most unit operations were represented, not all.	1. Recycling of overhead products not entirely represented.	1. All the images were copied from the Process Flow Diagram (PFD).	6
Group 4	1. Failed to show the entire process clearly.	2. Some unit operations were missing.	0. Failed to represent any optimisation element.	1. Most images copied from the level example	4
Group 8	1. Missed some parts of the process.	1. Failed to show most unit operations	0. Failed to represent any optimisation element.	1. Many images copied from the level example	3
Group 9	3. Well organised.	3. All unit operations were represented.	2. Showed recycling but missed some steps.	2. Interactive elements incorporated in the process creatively, but some images were copied from the level example.	10
Group 10	3. Well organised.	2. Failed to clearly represent all unit operations.	2. Showed the recycling process but missed other optimisation elements.	3. Creative level with original pictures.	10
Group 12	1. Incomplete process. Game design didn't account for the entire production process.	1. Failed to show most unit operations.	0. Failed to represent any optimisation element.	1. Most images copied from the level example.	3
Group 13	1. Misplaced the positions of the unit operations in the process.	2. Failed to represent some unit operations.	0. Failed to represent any optimisation element.	1. Most images copied from the level example.	4
Group 15	1. Failed to clearly show the entire process. Unit operations not obvious.	1. Failed to show all unit operations.	0. Failed to represent any optimisation element.	3. Creative level, genuine pictures.	5

Appendix B

Interview and survey

1. Link to study one's interview

2. Link to study three's post-creation survey

Appendix C

Levels' gameplay videos and the G.E.L.

1. Group 1
2. Group 2
3. Group 4
4. Group 8
5. Group 9: CHEM Jam winner
6. Group 10
7. Group 13
8. Group 15

The Game Editor for Learning webpage (includes download files and instructions for macOS and Windows, tutorial, and assessment template).

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