CHARMING
EU MSCA-ETN

Policy Brief 2

January 2023

Mechanics, Accuracy and Assessment in Immersive and Game-Based Education

Daniel Cermak-Sassenrath,
Center for Digital Play,
ITU Copenhagen,
DK

Tom Van Gerven,
Dept. of Chemical Engineering,
KU Leuven,
BE

Jarka Glassey,
School of Engineering,
Newcastle University,
UK

Ilse Smets,
Dept. of Chemical Engineering,
KU Leuven,
BE

Introduction The rapid increase in the use of immersive technologies and gaming in education and training at all levels raises a number of important issues, not only for the educators and training providers, but also for policy makers in this important area of human-resource development. The CHARMING project, funded by the EU H2020 MSCA ITN programme[1], set out to explore a number of these important issues across primary, secondary, and tertiary education, as well as lifelong training. This policy brief highlights the major findings of the project across various levels of education and training, which are intended to aid policy makers in formulating their policies for effective and efficient application of these technologies in education and training. Further details and scientific underpinnings can be found in the publications resulting from the CHARMING project and in the discourse, as referenced in this brief. Three important topics in immersive/game technology development and application in education are discussed, highlighting issues to be considered and proposing directions of travel, as evidenced by the CHARMING research, to guide the policy makers in their decision making.

1. European Training Network for Chemical Engineering Immersive Learning (CHARMING) website, https://charming-etn.eu

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

Integration of (Game) Mechanics and Content

It is broadly assumed that a key aspect of successful educational game is the integration of educational content with game mechanics. That is, to embed core learnings with game mechanics, to produce a 'congruent match' (Thrower, 2022) between content and game play. The notion of intrinsic integration was coined by Habgood et al. (2005) who refers to how learning content is integrated within the gameplay of serious games. Habgood explains that to achieve this a game needs to (i) "deliver learning material through the parts of the game that are the most fun to play, riding on the back of the flow experience produced by the game, and not interrupting or diminishing its impact"; and (ii) "embody the learning material within the structure of the gaming world and the player's interactions with it, providing an external representation of the learning content that is explored through the core mechanics of the gameplay". Their theory is illustrated using examples of a range of games, some directly relevant to chemistry and chemical engineering teaching (central to CHARMING project), e.g. Habgood and Ainsworth (2011) and Plass et al. (2015, p. 268).

Close and natural integration of (external) content and game (mechanics) is desirable for games people should be playing. The idea is, that the integration transports the (useful) message effectively and relatively effortlessly to the players. They then learn (about a real-world issue such as chemistry) or change their behaviours (e.g. lab safety) by playing. The results of the CHARMING project indicate that when the educational strategy is game-making (as opposed to game-playing), the quality of the game or of the integration is less relevant to the success of learning as the important transfer happens during the creation process (not during playing). The students who design the game learn from the design of the game, and during the design stage. The gap between the source domain (such as chemistry or chemical engineering) and the target domain (such as platform games) needs to be competently addressed and mitigated. This process invites and necessitates a considerable level of understanding on the part of the learners. (Fornós, 2022, pp. 5f.; Gee & Tran, 2015; Kafai & Burke, 2015).

Scientific Accuracy and Learner Engagement in Playful Educational Applications

Often a trade-off or tension can be observed in educational media between accessibility, attraction, simplicity, engagement; and accurate, scientific, complete or comprehensive representations. Simplification and abstraction are not only unavoidable when designing media, but can also be a desirable asset, to clearly focus on some aspects of a situation, and to omit others. Oversimplification, of course, can also be problematic, specifically in educational contexts and applications as misconceptions in learning may arise.

The trade-off is not a simple opposition of game design requiring easy access for engagement and content requiring absolute scientific accuracy. Simplification is often required by pedagogical considerations e.g. with regard to progressing from early understandings of 'ideal' concepts to more complex ones, and games need depth and complexity, too.

A number of CHARMING project outputs clearly demonstrate the need for various trade-offs under different circumstances. For example, Bunno's Fabulous Soap-Making Challenge (Cermak-Sassenrath et al., 2022, Domínguez Alfaro et al., 2022; **Figure 1**), promoting the learning of aspects central to the soap-making process, demonstrates the simplification requirement (Cermak-Sassenrath et al., 2022). First, a decision for one specific chemical process to create soap has been made. Secondly, the range of available equipment and raw materials in the game has been limited. Thirdly, the properties of the items in the game have been simplified and abstracted. The world surrounding the game is outlined only; delivery times, e.g., of materials, taxes, hiring of workers and variable prices, and many other aspects are omitted in order to promote playability.

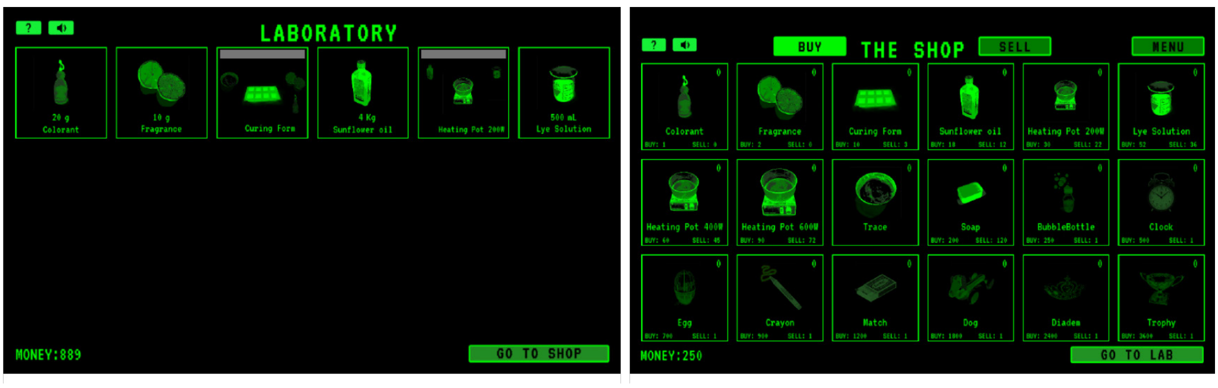

Figure 1. Bunno's Fabulous Soap-Making Challenge: The lab with materials and equipment (left); and the in-game shop (right)

Designing an AR application for a chemistry experiment (another CHARMING output) implies important considerations regarding content simplification. In general, procedures can be reproduced in virtual scenarios with virtual metaphors, but these do not necessarily transfer to the real world, and this can cause the learner unnecessary frustration. Not only is fidelity lost when learning content is translated into the digital realm such as VR applications, but also some extra challenges are added. For example, in the MAR Lab (Domínguez Alfaro et al., 2022), interactions are intended to be authentic, but opening a bottle of chemical reagent in the AR scenario is not always "logical" or "natural" for students. In real life, a student would not be explicitly taught how to operate bottles, but in the virtual scenario, users are not used to performing this action therefore, instructions are necessary. As a result, the number of instructions that need to be given to learners increases.

In engineering education, simulations of various processes using accurate simulators (e.g. baedon computational fluid dynamics, CFD) are increasingly required for better understanding of process performance/behaviour (Wilkes & Birmingham, 2006). However, incorporating such complex simulations into gaming environment required careful considerations of implementation and simplification, as highlighted by Solmaz and Van Gerven (2022).

A clear indication of the trade-off between the simplification and misconceptions is also illustrated in a board game to introduce primary school children to concepts about atoms, developed as part of the CHARMING WP1. The educational goal of the game is to acquaint the children with the idea that atoms (i) are building blocks of macroscopic s and (ii) the strength of bonds between atoms results in different degrees of hardness of materials. Currently, there is no defined way how to best teach concepts of atoms to young learners that have no prior knowledge of atoms. In a previous version of the game, atoms looked like spheres of sponges, stone, and steel (**Figure 2**). This feature was initially designed to evoke a connection between atoms and the materials out of which that robots are constructed. To avoid the misconception that atoms are 'just' small pieces of macroscopic materials, atoms are now given colours unrelated to familiar macroscopic materials, and each different atom has different bonding capacities.

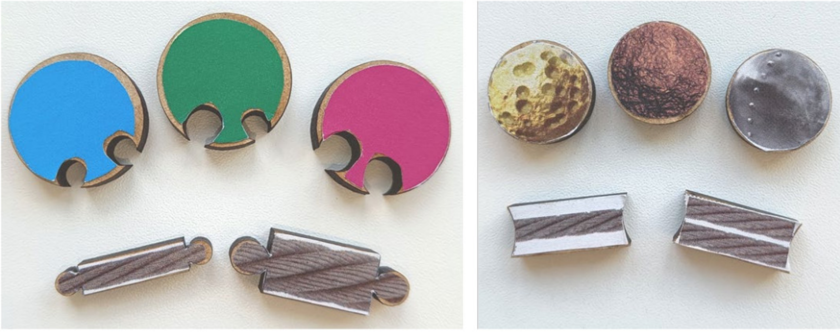

Figure 2. Material Monsters: Tiles for atoms and bonds

Assessment Concepts, Frameworks and Practices

Whilst the previous topics concentrated on the development of immersive educational and training tools, it is essential to account for appropriate assessment using these tools. Teaching methods and learning outcome assessments have been developed together and correspond well to each other. If one is changed, it is likely that the other needs revision. Assessment of learning (e.g. in curriculum-based education) should reflect what new educational media afford (i.e. new media are not meant as direct substitution for classic teaching media). Likely there is an overlap of the learned content between traditional teaching and new possibilities. But learners also learn different content, and in different ways, and with different emphasis, with implications for assessing the learning. New media may also require or offer new forms of assessment and feedback (e.g. through data/learning analytics).

One key advantage of digital immersive learning environments, such as VR simulation-based training environments or AR serious games, is that they enable the automatic measurement, collection, analysis and reporting of learner data through learning analytics systems. Learning analytics systems, such as a learning analytics dashboard, can visualise vital learning process information to support stakeholders, such as students/trainees or teachers/trainers. Visualising tailored information derived from learning analytics can help stakeholders make evidence informed decisions about future learning or learning design processes. However, the usefulness of learning analytics is limited by the quality of the data being collected and the processes of analysis.

Immersive technologies provide unique opportunities to measure what students can do by applying their conceptual understanding of subject matters, rather than what they say or their responses to traditional exam questions. With immersive technologies, students can demonstrate higher-order cognitive processes in their interactions within the environments, and these can be used to measure complex knowledge and skills that would otherwise be difficult to measure. However, because immersive technologies are relatively new in the classroom, they are often still being treated as "black boxes" by educators and researchers. Previous reviews of the literature showed that traditional assessment methods such as the use of tests are still overwhelmingly used when teaching with these technologies.

Although a few assessment design frameworks and guidelines such as the Evidence-Centred Design (ECD) and Information Trails have been presented and applied to assessments in digital games, they are generally considered complex to use, effective for use during the design phase of the environment and require advanced statistical skills. For wide adoption and broad impact of immersive learning technologies in Higher Education, the procedure for the assessment of learning must be clear, simple and educator-friendly. A robust assessment framework that can be applied to the design of both external and embedded assessments would certainly promote the use of immersive learning technologies for performance assessments. Assessment design frameworks for educators should demonstrate how to design authentic performance assessments that can be used to measure high order learning in immersive environments. Such a framework must capture all the elements necessary to design embedded (in-game) and external (traditional) assessments, and should ensure appropriate alignment between these for the measurement of the desired learning outcomes. CHARMING project outputs include a new assessment framework for game-based learning that has been tested both on pre-existing and de-novo designed serious education games (Udeozor et al., 2023a, Udeozor et al., 2023b).

Key project information:
Project type: EU H2020 MS-CA-ETN
Project duration: 4 years (2018-11-01 to 2022-10-31)
Website: http://charming-etn.eu
EU contribution: €4.06 m
Coordination: KU Leuven

Conclusions

Societal gain and prosperity are shown to be reached when transformative change of future education accelerates faster than future technology (OECD, 2020). It is thus essential that policy makers support and encourage the adaptation of new technology in education and training to facilitate this. The presented policy brief provides policy makers with important insight into aspects of immersive and game-based learning that need to be carefully considered to ensure effective application of these new educational technologies. It also provides useful references to case studies and practical demonstrations of these issues.

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