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A video game as an assessment tool of problem-solving competence

Motivation:

Problem-solving (PS) is one of the most important skills in chemistry education. The structure of scientific problem-solving consists of four empirically-distinct processes or dimensions: understanding and characterisation, representation, solving the problem, and reflection and communication (Wüstenberg, Greiff, & Funke, 2008; Scherer & Tiemann, 2014). Consequently, the assessment of PS in educational settings should occur in environments capable of systematically handling different processes (dimensions) as opposed to individual tasks that demand only one specific cognitive action. Therefore, virtual micro-worlds or simulations are especially appropriate for assessing PS competence (Leutner, 2002; Scherer, Patzwaldt, & Tiemann, 2012; Wirth & Klieme, 2003). It has been shown that computer games can help educators determine not only students' current levels of problem-solving, but also students' strengths and weaknesses in a particular phase of problem-solving (Shute et al., 2016). In addition, implementing gamification elements in the game has a potentially positive impact on student motivation (Alsawaier, 2018; Hamari & Koivisto, 2015). Building on the gamification approach, the research idea specifically showcased the design of a video-game, based on the four scales of the problem-solving model (Koppelt & Tiemann, 2008), with three levels of proficiency to investigate if this new application form is valid, not only for motivating and engaging students but also to assess the students' performance in problem-solving competence in chemistry education.

Theoretical background

Problem-solving is defined as, "an individual's capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious. It includes the willingness to engage with such situations in order to achieve one's potential as a constructive and reflective citizen. (OECD, 2003, p. 156)

To solve chemistry problems, students have to follow scientific steps or a scientific model, for instance, the competence model with four phases (Koppelt & Tiemann, 2008; OECD, 2013; Scherer & Tiemann, 2014): 1) understanding and characterising the problem (PUC), 2) representing the problem (PR), 3) solving the problem (PS), and 4) reflecting and communicating the solution (SRC). The problem-solving competency is necessary along with the in-class communication between pupils and elevated motivation (Jonassen & Kwon, 2001). Therefore, it is important for educators and teachers to assess students according to their problem-solving competence. Assessing means collecting and analyzing student's data regarding their understanding or their performance (Shute & Wang, 2009). Paper-pencil is one of the assessment tools for superficial skills. Therefore, the focus goes toward computer-based assessment, since it allows students to interact with the system. MicroDYN is one example of a computer-based problem-solving assessment which is a linear structural equation. Another example is the "Use your brain" assessment tool for PS in mathematics. Researchers argue that well-designed video games are a successful educational and assessment tool for problem-solving competence (Shute et al., 2016). It has been shown that computer games can help educators determine not only students' current levels of problem-solving, but also students' strengths and weaknesses in a particular phase of problem-solving (Shute et al., 2016). The gamification concept came from games, and refers to "the process of adding game mechanics to processes, programs, and platforms that would traditionally not use such concepts" (Swan, 2012, p. 13). There are two types of gamification: structural and content gamification. The choice of the most suitable form of gamification depends on the cost, required time and the type of content that the instructor wants to offer to learners (Pastor Pina, Satorre Cuerda, Molina-Carmona, Gallego-Durán, & Llorens Largo, 2015). Structural gamification is an application of game elements to the environment of any activity without the alteration of the content. Content gamification is the application of game elements and game thinking to modify the content. This modification makes the content more game-like but does not turn the content into a game. It simply provides context or activities which are used within games and adds them to the content being taught. In this case, to gamify is equivalent to addressing a problem like a game designer, using all resources you can muster to create an engaging experience that motivates desired behaviours (Werbach & Hunter, 2012). Game elements are the main part of the interaction between the game and game players; they affect the playability of a game directly (Dubey, Chavan, & Patil, 2016). It includes three attributes: Dynamics, Mechanics, and Component. Werbach and Hunter (2012) have created a model of the game elements and components in the form of a pyramid, as shown in Figure 1, which was chosen for this research because it covers the abstract levels of the dynamics and mechanics elements and also the components. In the game elements model (Figure 1), the highest level of thinking is Dynamics, then the Mechanics come as the second level and the Components are the third and final level. The highest level directs the lowest level and many of the components of the lower level can be used to achieve the goal of a higher level. The game design must always start from the highest level, making a clear decision on what the basic dynamics of the game will follow. Then, the Mechanics are decided based on the chosen Dynamics elements and how they fit together in the game concept. Finally, the game components can be chosen based on the Dynamics and the Mechanics elements. It is not required to use all the elements and components of the game, but it is important to think about the core things that make the game achieve its goal and lead to the fun (Werbach & Hunter, 2012). In order to design an educational video game as an assessment tool of problem-solving competence, it required applying the problem-solving model in a game design model following the gamification approach. This highlighted the need to address the research question:

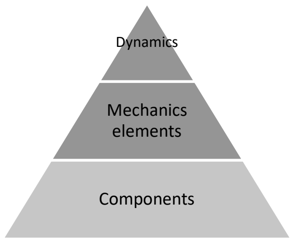

Figure 1. Game elements (Werbach & Hunter, 2012)

How should be a video game be designed on the principles of gamification to assess problem-solving competence in the domain of chemistry?

Design and development the game

To answer the research question, the design science research methodology (DSRM) was followed. DSRM helps to design and validate a new artefact. In this research, the artefact is the “ALCHEMIST” game that should assess the problem-solving competence in chemistry education. To design and develop the game, the model created by Zin, Jaffar & Yue (2009) was adopted to develop the game with gamification elements as an assessment tool. The design and development went through five phases (see Annaggar & Tiemann, 2019).

In the analysis phase, as a starting point, nineteen pupils and seven experienced teachers were interviewed as future users of the game, to understand their needs and to focus on the game design idea. The results helped to design the game according to their needs as shown in Figure 2.

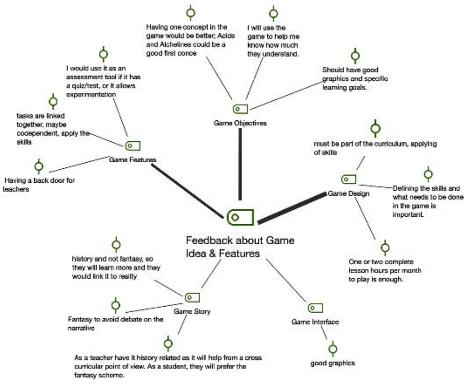

Figure 2. Code-Subcodes-Model” about teachers´ feedback to the initial idea of a video game for learning science

In the design and development phases, we were keen to follow and implement a problem-solving competency model using different game elements. The assessment of the problem-solving competence is done through the provided tasks, multiple-choice questions, open-end questions, and problem-solving questions with three levels of proficiency (Figure 3). The quality assurance was done by four chemistry education researchers to check the game content and the development errors. Lastly, the evaluation is done by three 9th grade students to make sure that the game is working and that it is easy to use by students.

Figure 3. Screenshot of ALCHEMIST

To validate the design, a quantitative study was conducted with students using the ALCHEMIST game and MicroDYN to see if there is a correlation between the results from both tools.

Validation study

In this study, we tested the correlation between the ALCHEMIST game and MicroDYN. The purpose of this study was to validate the ALCHEMIST game and explore its effect on students' content knowledge. The study utilised quantitative data obtained from the pre-test, the ALCHEMIST game scores, MicroDYN results and the post-content knowledge test (Figure 4).

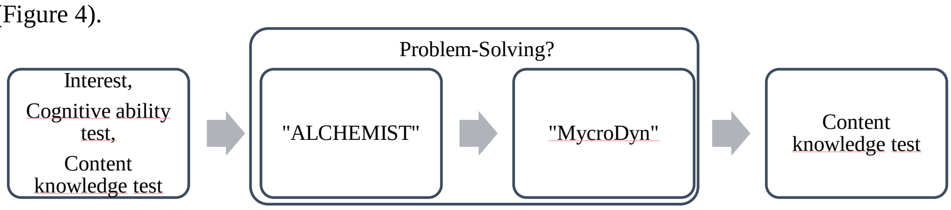

Figure 4. Validation study design

The study was conducted in three 8th grade classes with 75 students. The pre-test measured students' interest (seven items of PISA scale 2006), cognitive skills (25 KFT test items) and their prior content knowledge (nine multiple-choice questions and one fill-in-the-blank question). The ALCHEMIST and MicroDYN were administered to assess the PS competence. Lastly, the post-content knowledge test was applied to explore if the students learn content after the gameplay.

Results

To establish convergent validity, we tested the correlations among the ALCHEMIST scores and the scores from MicroDYN. The results showed that the ALCHEMIST game is significantly positive fair correlated with MicroDYN ($0.21<r<0.4$). Thus, ALCHEMIST appears to be valid as an assessment tool of problem-solving competence.

We also found that there is a significant difference between students' scores of the content knowledge test before and after playing ALCHEMIST as shown in (Figure. 5). Thus, ALCHEMIST can be used as an eLearning tool for chemistry context.

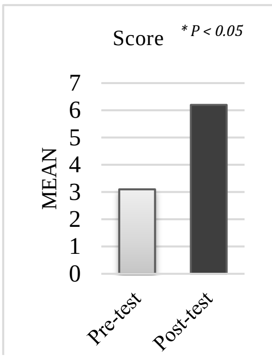

Figure 5. Pre and post test results

Acknowledgment

The authors thank the AK Tiemann and Dr. Zehl for their help with the design and development of ALCHEMIST. They also thank Prof. Dr. Priemer who collected the data in the UniLab Adlersof.

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