Abstract

Complex and dynamic contexts can be researched on a larger scale and extensively tested in real school settings. But in addition to the complexity and dynamics of problem-solving processes, another challenge still remains the motivation to deal with problems intensively and for a sufficiently long time. Using the approach of gamification in teaching chemistry, i.e. combining of game-based learning and the problem-solving processes in chemistry will enhance “chemistry education” using the motivational elements of “a game”. Until now, various studies focused on designing gamification models for education, but as far as the research started, no previous research has investigated to design a gamification approach to assess problem-solving competence in chemistry education. Following the gamification approach, both learning and assessment content can be integrated as well as promoted the ability to solve problems.

The present research aims to validate a framework for the theory-driven development and evaluation of video game-based on learning environments. This environment should enable an individual discussion of the learning content of acids, bases, and pH value, giving individual feedback for learners and having elements of gamification inside. This framework was designed based on the four phases of the competence model (Koppelt & Tiemann, 2008), with three levels of proficiency; self-determination theory and game design model, considering the central elements of gamification.

The Design Science Research Methodology (DSRM) was followed in order to design and validate the game framework. The design framework consists of the phases “Analysis", “Design", Development", “Quality Assurance" and “Evaluation & Implementation". The developed game is called "ALCHEMIST", which is a 3D adventure assessment game, consecutively for an average of an hour gameplay.

Consequently, a case study was conducted to evaluate ALCHEMIST, where nine think-aloud protocols were analyzed to observe the implementation of the competence model. Beside that, quantitative data was collected from 22 student teachers to evaluate the game design, goal, enjoyment, and implemented scientific content. The evaluation results revealed that the problem-solving phases could be observed during the gameplay, which confirms that the competence model was successfully implemented. Additionally, the student teachers agreed and satisfied with the game design.

After the evaluation studies, a validation study with 75 7th and 8th-grade pupils (13-14 years old) was conducted to validate ALCHEMIST as an assessment tool of problem-solving competence. The validation results validated ALCHEMIST as an assessment tool for problem-solving competence, where ALCHEMIST was correlated with MicroDYN (Greiff & Funke, 2009), and fluid intelligence. The collected data allows extensive and detailed analyzes of the problem-solving ability.

These results are a starting point for a new research field linking gamification to the assessment in chemistry education and its impact on various aspects.

Keywords Chemistry education; Educational game design; Problem-solving; Assessment; Gamification; Design science research

Zusammenfassung

Komplexe und dynamische Kontexte können zwar in größerem Maßstab erforscht und in realen Bildungssituationen hinreichend getestet werden. Neben der Abbildung der Komplexität und Dynamik dieser Prozesse (z.B. beim Problemlösen) bleibt aber auch die Motivation, sich intensiv und ausreichend lange mit der Testsituation auseinanderzusetzen, eine weitere Herausforderung. Die Verwendung des „Gamification“-Ansatzes in der chemiedidaktischen Forschung, d. h. die Kombination von spielerischem Lernen mit seinen motivationalen Elementen und der Erhebung von Problemlöseprozessen in der Chemie, bietet eine vielversprechende Option. Bisher konzentrierten sich verschiedene Studien auf die allgemeine Entwicklung von „Gamification“-Ansätzen, zur Verwendung dieses Ansatzes zur Erhebung oder dem Erlernen von Problemlösekompetenz liegen jedoch bislang kaum wissenschaftliche Untersuchungen vor.

Die vorliegende Studie fokussiert auf die theoriegeleitete Entwicklung, Evaluierung und Validierung einer videospielbasierten Lernumgebung. Diese Umgebung soll eine individuelle Diskussion über den Lerninhalt von Säuren, Basen und dem pH-Wert ermöglichen, individuelle Rückmeldungen für die Lernenden geben und Elemente des „Gamification“-Ansatzes enthalten. Die Problemlösekompetenz wurde anhand von vier Phasen mit jeweils drei Niveaustufen operationalisiert und in der Umgebung mit zentralen Elementen aus der Selbstbestimmungstheorie, dem „Gamification“-Ansatz und dem Spieldesignmodell ergänzt. Anhand der „Design Science Research Methodology (DSRM)“ wurde der Spielrahmen entworfen. Dieser besteht aus den Phasen „Analyse", „Design", „Entwicklung", „Qualitätssicherung" und „Evaluation & Implementierung". Die so resultierende spielbasierte Umgebung (ALCHEMIST) ist ein 3D-Abenteuerspiel, welches innerhalb einer Spieldauer von ca. einer Stunde die Problemlösekompetenz erhebt. Dazu wurden die Ergebnisse mit solchen durch MicroDYN (Greiff & Funke, 2009) erhobenen Daten verglichen und die Fluid Intelligenz kontrolliert (n=75). Die gesammelten Daten ermöglichen eine umfassende und detaillierte Analyse der Problemlösungsfähigkeit. Sie sind ein Ausgangspunkt für weitere Forschungen, die den „Gamification“-Ansatz mit „Stealth-Assessmentt“ Methoden verbinden. Für detaillierte qualitative Einblicke wurde eine Fallstudie zur Einschätzung von ALCHEMIST durchgeführt (n=22). Dort wurde das Spieldesign, die Zielsetzung, den Spielspaß und die implementierten wissenschaftlichen Inhalte durch Fragebögen und zum Teil Think Aloud Protokolle (n=9) erhoben. Die Evaluationsergebnisse zeigten, dass die Problemlösephasen während des Spielens beobachtet werden konnten und das Spieldesign ansprechend war.

Diese Ergebnisse sind ein Ausgangspunkt für ein neues Forschungsgebiet, das die Verwendung von Gamification-Elementen zur Vermittlung und Bewertung von Kompetenzen im Chemieunterricht umfasst. Es lassen sich diverse Implikationen für andere Themenfelder ableiten.

Schlüsselwörter: Chemieunterricht; Lernspiel Design; Problemlösung; Bewertung; Gamification; Design Science Research

1 Introduction

This thesis considers the field of chemistry education as the main subject of its study, where Problem-solving (PS) is one of the most important skills in this field. The structure of scientific problem-solving consists of four empirically-distinct phases or dimensions: understanding & characterization, representation, solving the problem, and reflection & communication (Wüstenberg et al., 2012). Consequently, the assessment of PS in educational settings should occur in environments capable of systematically handling different phases (dimensions) as opposed to individual tasks that demand only one specific cognitive action.

The traditional assessment tools like short answers questions and multiple-choice questions mainly analyze the superficial skills. They are not valid for going through the main context in which competencies and knowledge are being smeared (Shute & Wang, 2009). Additionally, in chemistry education, the increase of the difficulty and complexity of the problem has led to an increase in the number of assessment items (Jonassen & Hung, 2015; Van Merriënboer & Kirschner, 2017) that could affect pupils' motivation due to existing complexity of the problem and increase in the assessment time. For instance, the assessment time is given to attempt a problem-solving booklet test that could reach two hours (OECD, 2012).

Researchers emphasized that problem-solving competence can be fostered as well as assessed through playing the well-designed video games due to the interaction between the game and the player (Annaggar & Tiemann, 2017; Shute & Wang, 2009; Shute, Wang, Greiff, Zhao, & Moore, 2016). It has been stated as the usage of the video games that combines with the enjoyment as well as learning simultaneously (Angawi, 2014). While stimulating the main enjoyment gained from the game within the learning process. The game is referred to the artwork that involves players within an artificial conflict. Games are defined by a set of rules and regulations that are required to be followed in order to assess the intended outcomes and results at the end Crawford (1984). Video games are mainly designed to provide an interactive

environment to motivate the pupils in order to learn and grow within chemistry education. Video games can help enhancing the cognitive skills like critical thinking as well as problem-solving competence. Moreover, it usually shows the learning process beneficial for the pupils that are interested in chemistry education (Groff, 2013). Likewise, video games could help educators determine not only pupils' current levels of problem-solving, but also pupils' 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 pupils' motivation (Alsawaier, 2018; Hamari & Koivisto, 2015). This is due to the video games that consists of many characteristics like interactivity, emotional reaction, challenge, control, abstract, feedback, aesthetics as well as quantitative outcomes for the learning process. Video games consist of many components such as leaderboards, levels, points, avatars, tasks and several other components where pupils are capable of having interaction with the game and keeping themselves motivated (Bromana & Mårell-Olssonb, 2018). With the help of combining the characteristics and components of the game and then applying it to various aspects, can motivate the pupils and improve the competence of problem-solving.

One primary problem with assessing problem-solving competence in chemistry education is the lack of the interactive assessment tools. Where, virtual micro-worlds or simulations are especially appropriate for assessing PS competence (Leutner, 2002; Scherer et al., 2012; Shute et al., 2016). Another challenging problem which confirmed in this domain is losing the motivation when the test is very long, or when the pupils find a certain subject difficult (Scherer et al., 2020). The inability of the pupils to concentrate for a longer period of time is also observed (Flanagan & Roseman, 2011).

One suggested way to overcome these problems is to revise interactive assessments and associated tools. A solution to this problem is proposed in designing and developing a gamification framework as an assessment tool for problem-solving competence. Hence the main question on which this research was based emerged to be answered was: how should a video game be designed on the principles of gamification to assess problem-solving competence in the domain of chemistry?

A crucial work for exploiting the advantages of technology-supported assessments of problem-solving competence in combination with motivational elements of game-based learning is the design and the validation of the video game. Wherefore, the aim of this work is to showcase the design of a video game-based on the four scales of the problem-solving model (Koppelt & Tiemann, 2008), with three levels of proficiency. The investigation is to examine if this new application form is valid, not only for motivating and engaging pupils but also to assess the pupils' performance in problem-solving competence in chemistry education. For this purpose, this

research focuses on the validation of a model for the theory-driven development and evaluation of video game-based learning environments. These environments should enable an individual discussion of the learning content, give individual feedback for learners and have elements of gamification inside. Moreover, the research will evaluate the effectiveness of establishing the framework of the game. Following this approach, both learning and assessment content could be integrated as well as promote the ability of solving problems (McFarlane et al., 2002; Shute et al., 2013). The assessment takes place in a video game either openly about questions to be answered or “hidden" about tasks or challenges dealing with the game content by so-called “stealth assessment" (Shute & Ventura, 2013). The core objectives are:

- Identify the design solutions that are applicable for the development as an assessment tool.
- Identify the scientific content within the design solution that is related to the chemistry learn the plan of high schools.
- Evaluate the effectiveness of the design solution that is based on the competence problem-solving model.
- Ensure the adaptability within design a solution, while implementation of the motivational frameworks.
- Ensure that game design must enable the pupils to use it easily and get engaged with the different tasks of the game.

The significance of the study is to implement the gamification approach in the chemistry education field. It has been seen that approximately 81% of the pupils studying in high school are playing the video games and it is said to be worth if they use the game as the process of learning and it will motivate the pupils to learn and increase their interest in chemistry education, in addition to being helpful in the assessment process of problem-solving. A design science approach has been selected for this research, particularly due to the development of the new artifacts within the education of chemistry.

Outline of the Research

The first chapter (Chapter 1) demonstrates a brief background about the research, aims and objective, research questions, the rationale of the research, significance of the research, problem statement and conceptual framework. The second chapter (Chapter 2) will demonstrate the literature review that will be gathered from different research areas that have been conducted previously on the intended topic. The third chapter (Chapter 3) will focus on the methodology and the process that will be used within the research. It is mainly followed by design science research as an

approach. The fourth chapter (Chapter 4) will be based on designing gamification framework. The fifth chapter (Chapter 5) will be based on demonstration and results. The sixth chapter (Chapter 6) will state the discussion that is supporting research and results gained from chapter five. The last chapter (Chapter 7) is a conclusion that will conclude the overall findings and further implications of the research.

2 Literature Review

2.1 Introduction

This chapter examines the literature pertinent to problem-solving competence, problem-solving assessment, game-based learning and gamification, learning and motivation theories, and the design and development of video games to assess pupils' ability in problem-solving. It begins with a conceptual overview of problem-solving competence, where Section 2.2 and Section 2.3 discusses the assessment of problem-solving capability by reviewing some assessment tools. Section 2.4 discusses the definition of gamification and presents the gamification elements and case studies of gamification. Section 2.5 is an overview of the learning theories, that focus on the constructive learning theory in educational games. 2.6 clarifies the design models of video games in education and how to develop them. The research gaps and the research questions are presented in Section 2.7, where the objectives and the significance of the research are presented in Section 2.8. Lastly, the summary is given in Section 2.9.

2.2 Problem-Solving Competence

Problem-solving competence holds a significant place in chemistry education, which allows the pupils to drive their individual thought process towards enhanced learning and its application to solving problems in diverse situations. Pupils apply this skill when they face a perplexing situation, which necessitates them to relate their formerly acquired knowledge for addressing an issue previously dealt with (Kapp, 2012).

Problem-solving competence is considered as a fundamental concept in education, such as the pupils learning chemistry education that is required to develop problem-solving competence simultaneously for dealing with the subject-related learning issues.

According to The Program for International Student Assessment (PISA), English language competence as the acquisition of skills, that are needed to communicate in English successfully e.g., reading, listening, writing, and speaking. PISA (2015) defines problem-solving competency 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 to achieve one's potential as a constructive and reflective citizen" (OECD, 2004a, p. 156).

The researchers have extended the concept of problem-solving competence to the advanced tier named CPS. It shows how this skill could help the learner in gaining implicit and explicit knowledge along with the systematic strategy selection for devising an appropriate solution process (Fischer, Greiff, & Funke, 2012; Sonnleitner, Brunner, Greiff, Funke, Keller, Martin, Hazotte, Mayer, & Latour, 2012).

Likewise, researchers have also discussed the effectiveness of the learning and assessment approach for CPS such as problem-solving, through a computer-based microworld (e.g., the genetic lab) (Sonnleitner et al., 2012). Hence, problem-solving competence drives the pupils to apply their original thinking for and issue to a new and innovative design. The application of original thought could be attributed to the use of creative and critical approaches to direct the physical as well as emotional competencies for reaching towards efficient solutions (Surif et al., 2012).

The goal of the chapter is to review existing literature on the shared definitions, theoretical frameworks, and problem-solving models, to gain a comprehensive overview of the problem-solving competence, and for making subsequent connectivity among problem-solving competence and chemistry education.

2.2.1 Definition of Problem and Problem-Solving Competence

According to Duncker & Lees (1945), the root reason behind the occurrence of a problem stems from the situation where an individual has a goal, but the solver is not aware of how to reach it. On the contrary, Newell & Simon (1972) stated that the problem occurs when the solver attempts to perform a task without knowing the exact steps or actions needed for the solution. Similarly, Jonassen (2004) defined a problem as the gap between the encountered situation and the desired situation where an individual wants to be. However, Duncker & Lees (1945) explained the complexity involved in transiting from the given situation towards the desired outcome, and according to them, merely a simple action is not adequate for such transition. Instead, an extensive recourse towards thinking is required for effective results.

For a more distinctive definitional view of the 'problem', Jonassen (2004) exhibited further the critical categorization of the problem characteristics. Firstly, the author