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Digital game-based examination for sensor placement in context of an Industry 4.0 lecture using the Unity 3D engine – a case study

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Abstract

Due to the many advantages that digital teaching and testing methods have over traditional ones, they are increasingly finding their way into everyday educational practice. The current events of the COVID-19 pandemic have given these approaches an additional boost. In this paper, a first version of digital game-based examination for sensor placement is presented, which can supplement parts of a classical exam for an Industry 4.0 lecture designed for postgraduate engineering students. For the development of the environment the Unity 3D Engine as well as freely available models and plugins for Unity are leveraged. By doing so, an immersive virtual scenario is created in which complex problems can be depicted and solved by the student. To ensure the suitability of this exam type and the coverage of the desired learning objectives, an evaluation of the game-based examination environment will subsequently be conducted and the results are discussed.

Keywords: engineering education; digital game-based learning; game-based assessment, gamification; Unity, Industry 4.0

1. Introduction

New disruptive technologies are increasingly finding their way into various areas of our society and opening completely new possibilities. As for education one of the technologies that have had an impact is the use of virtual worlds for digital game-based learning (DGBL) environments [1]. In general game-based learning combines knowledge transfer with interactive game environments to create a learning situation in which a higher motivation, engagement and enjoyment for the student can be realized leading to better learning effects [2]. This is because conventional teaching methods are mostly passive and aim at passing an exam rather than developing a complete understanding of the subject, whereas in DGBL the students actively participate in the learning process fostering the comprehension of the topic as well as their own problem solving skills [3]. Another advantage of DGBL is that complex subjects become more presentable and accessible by creating an environment in which real life situations can virtually be recreated and simulated [4,5]. These virtual environments can not only be used in the teaching context, but also to test the students, which is referred to as game-based assessment in the literature [6]. In this context, there are also advantages over conventional forms of examination, such as pen-and-paper examinations, since the students answer tasks in different scenarios that are close to reality. This again allows a more accurate assessment of the student's actual skills and knowledge. Altogether this has led to a risen interest in the use of DGBL as well as game-based assessment in the educational sector [7].

Against the backdrop of the current events of the pandemic, this fact has become even more important, as digital teaching and examination methods have gained further significance as a result. With the outbreak of the COVID-19 pandemic and the associated lockdown in spring 2020, universities around the world were faced with major challenges. To limit the further

spread of the virus, lectures were mostly held online and on-site exams were either reduced in number of present students, cancelled, changed to another exam type or conducted online [8]. Because of the digital nature of DGBL and assessments, they can be transferred to students' homes more easily than conventional approaches, reducing overhead. There are various market-ready software systems to make digital exams safe [9,10] and avoid cheating by the students, not only when the examinations are conducted at the university with internal equipment but also for running them on the students' devices [11]. This creates opportunities to enable safe exams without students being present at the university and at the same time to transfer the digital materials from DGBL into exam scenarios.

For these reasons, this paper presents a case study of a digital game-based learning environment that can be used as a part of an online or digital examination developed with the Unity 3D engine. The game can be used in combination with examination software systems and was evaluated in a study after finalization of the first version. In the following chapters, the developed digital game-based examination will be abbreviated as DGBE.

2. Essentials

In this chapter, the basics necessary for understanding the DGBE are explained in more detail. For this purpose, the didactic essentials are explained with focus on the fundamental use of games in the education sector by examining digital game-based learning and the associated approach of gamification. In the following chapter, a taxonomy for learning objectives is presented, which is used for the evaluation of the addressed objectives in the DGBE. Secondly, the software basics are explained. For this, the general game development process is shortly specified and the Unity environment is explained with the help of which the implementation of the DGBE takes place.

2.1. Didactic essentials

2.1.1. Digital game-based learning (DGBL)

DGBL is an approach mostly influenced by Prensky who defined it as a synthesis of computer games and a variety of educational content. It has the goal to achieve better learning results by engaging students and as a result making the learning process fun and entertaining. Instead of putting the teaching at the center of attention, it takes a student-centric turn enabling learning through discovery, interaction and curiosity. There are several areas that DGBL can be used for such as dry material, difficult subjects, complex problems or strategy development [2,12].

To accomplish a well-designed DGBL environment that achieves a high learning effect Gee described three main areas which encompass thirteen principles. Within the first area "learner empowerment" the principles focus on enabling the player to create his individual gaming experience. The player should have the feeling that their decisions are the main factor of their experience and that they are free to play the game as they like. Moreover, the player should be able to identify with the situation which they can alter by their actions. The area

"problem solving" outlines that problems should match the players' abilities instead of being too hard to solve while still providing the possibility to extend their skill set. These skills should be used to the advantage of the player and to develop a strategy for progression in the game. Furthermore the information provision is addressed so that information should always be provided when the player needs it to solve the given problems. Another main point is about giving an experimental space for learning to the player which has no negative consequences on the course of the game. The last area "understanding" proposes to closely link the game ideas to actual game elements and that the best learning results are created by the actual experience of the player [13,14].

As already mentioned, the successful implementation of DGBL into today's education aims at the enhancement of motivation and engagement, but it offers some more crucial benefits going beyond that. By shifting the learning to an interactive and self-driven process, cognitive as well as advanced decision making and problem-solving skills are promoted. Students are faced with an immersive digital environment where they can recognize themselves and make independent progress which reinforces their digital literacy, self-esteem and autonomy [15,16].

As DGBL can be easily formed to a digital assessment, it bears the potentials of computer-based testing such as automatization of the evaluation procedures, standardizations of scorings and interpretations of the test results [17]. Furthermore, game-based assessments offer the possibility to place the student in an immersive experience with educational context while a large range of data about the problem solving process can be collected and real time feedback can be given back. By doing so, the educator is enabled to evaluate complex skills and competencies which could not be measured that easily by traditional assessment forms e.g. by multiple choice tests [18].

2.1.2. Gamification

Gamification is described by Deterding et al. as using game design elements in context other than games [19]. The aim behind this concept is to increase the engagement for the user within a gamified application. In contrast to DGBL which is only used in the educational sector, gamification can be used in various other fields such as the gamification of corporate collaboration-software to amplify employee interactions or in marketing to boost the time a buyer spends in an app [20,21].

To implement the elements of game design the Mechanics, Dynamics and Aesthetics (MDA) framework defined by Hunicke et al. can be leveraged, helping the game designer meet the demands of the player [22]. In the MDA, mechanics characterize the underlying elements and schemes of the game which define the framework of the player's actions as well as for the progress. Common examples for game mechanics can include points, timers, quests, levels, and achievement systems. Dynamics are built on these mechanics and can be described as the executed behavior during the gameplay of them using the player's actions and the interaction among players as an input. Aesthetics on the other hand outline the desirable emotional responses of the player when interacting with the game system and thereby are the fundament of the players' experience.

Possible desirable emotions that can be evoked include challenge, creativity, sensation or discovery [20,22,23].

A sharp distinction between the terms gamification and DGBL is difficult to make, as both aim to increase user motivation and involvement using game-based methodologies and thinking [24]. However, the two approaches can be distinguished based on the depth of implementation. While DGBL results in a full-fledged game, gamification addresses individual elements and processes [19].

2.1.3. Taxonomy for learning objectives

A common approach to categorize educational learning objectives and examinations is the revised version of Bloom's taxonomy which was created by Anderson and Krathwohl [25]. It represents a hierarchical classifying system for the cognitive process dimension as well as the knowledge dimension. With the cognitive dimension focusing on the thinking abilities of the student and being the most known and relevant for this paper the following remarks will only focus on that dimension. The main idea is that the content that educators want students to learn can be arranged in a hierarchical order increasing in complexity, whereby each hierarchy level builds on the other. Students have to be proficient in the less complex level(s) before moving on to the next one. The six levels in ascending complexity are: remembering, understanding, applying, analyzing, evaluating and creating. The first level "remembering" aims at the student being able to retrieve material like facts, definitions or lists and reproduce it. Within the next level "understanding" students need to be able to construct a meaning from instructional messages whether they are in an oral, written or graphic form. "Applying" means transferring and using an acquired procedure in a given situation which can either be a familiar or unfamiliar task. Building upon this, the "analyzing"-level deals with breaking down material in parts and determining how they relate to one another and a common structure or purpose. When reaching the "evaluating"-level the student should make judgements based on criteria and standards which can for example be finding inconsistencies in products or processes or recognize the appropriateness of a procedure. The last and highest level "creating" focuses on putting elements together to a whole or reorganizing them to a new pattern [25].

2.2. Software essentials

2.2.1. Game development

User-centered software development methods often use an initial version of the software as a basis. With the help of user's or client's feedback, the software is optimized step by step via an iterative and incremental approach and further functions are added until the desired result is achieved. The initial version, which is referred to as a minimum viable product/ game (MVP/MVG) depending on the context, already contains the central functions of the application, so that it is possible to determine at a very early stage whether the software meets the requirements. The central idea of a MVP is to gather the maximum possible insights from the users or clients with a minimum of effort [26,27]. By acquiring feedback, a wide variety of aspects can be investigated, for example issues of the user experience, such as look and feel or intuitiveness. In addition, the user can be asked about the benefits of the software in order to evaluate it [28].

2.2.2. Unity Engine

To create virtual environments for DGBL and assessment applications the game engine Unity is frequently used in a number of publications, exploiting its' key features like basic physics or building options as well as a large user community [3,29–31]. Unity is the most widely used real-time game development platform with a range of various applications. Beside games it is also used in areas like manufacturing, cinematics, engineering or architecture [32]. It includes tools for creating multi-platform applications, allowing the creation of classic desktop games as well as game console, web, mobile and VR/AR applications [33]. For the implementation of web-contents the HTML5 based "WebGL" platform is used which runs in a regular browser [34].

The main development tool is represented by the Unity Editor which allows the user to create the virtual environments by adding game objects inside the scene. These game objects can represent characters, 3D-models, lightning, cameras, and audio effects. Every game object can be further modified and so-called components can be added which can be used to alter specific characteristics such as physical properties, textures or materials. Since the creation of more complex game objects and components is limited to a certain point in Unity, there is an option to import them as an asset either from other programs, e.g. 3D-models from Blender, or from the Unity asset store. Inside the store different developers offer their assets for free or against payment and they can directly be downloaded and used [35]. To implement the game logic itself Unity uses scripts written in the object-oriented programming language C# and developed in Visual Studio Community by default [34].

3. Development of the DGBE

3.1. Background

The contents for the game are part of an existing postgraduate cross-university engineering lecture which is called "Industry 4.0 for engineers" and is held, among others, at the Technical University of Hamburg (TUHH) in different study programs. It gives a general overview over current topics of Industry 4.0 that are relevant for today's production engineering such as cloud technologies, sensor systems, robotics, artificial intelligence and human-machine interaction. In order to fully incorporate this content in a 1.5 hour exam, there is little room for the individual areas to pose complex questions. Therefore, the examinations only provide information about the basic skills of the students which can be found in the first two levels (remembering, understanding) of the presented learning objectives taxonomy. Thus, the current examination design only reflects the actual competence required of an engineer in the field of Industry 4.0 to a limited extent, since complex problem-solving strategies and the application of various methodologies are necessary for this.

For these reasons, a suitable form of examination must be developed for these skills, which, despite time limitations
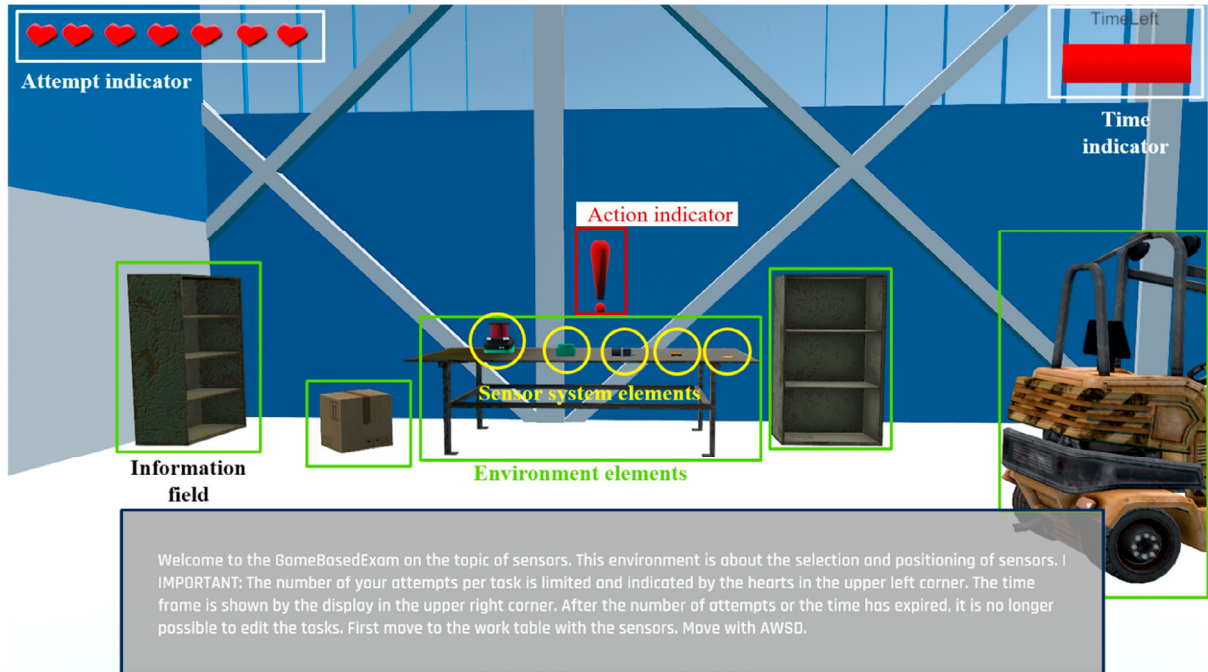
Fig. 1. Player view at the start of the game.

during the exam, allows the student a profound examination of a question. With the help of a digital examination form, which is based on the approach of a DGBL environment, this circumstance should be taken into account.

For the development of the game the contents of the lecture on the topic of sensor systems are used, in particular the selection and placement of sensors in Industry 4.0 environments. The focus of the game development is to create a MVP with the most essential features, which are basic movement within a 3D industrial environment, selection and placement of sensors, implementation and processing of multiple tasks and logging of the results. This MVP can be seen as the basis for an incremental and iterative software development approach, so that the game can be optimized and extended based on the feedback loops. To gather the feedback necessary for this approach an evaluation of the MVP by the users, which are the students in this case, is presented in chapter 4. The last point to be investigated in this project is the integration into a digital exam. Therefore, the combination of the developed game with a secure examination software is to be examined.

3.2. Learning objectives

The aim of the DGBE is to give the student a chance to prove a deeper understanding of sensor systems in the context of Industry 4.0 than with the previous "pen and paper" exam tasks. The main (high order) learning objectives which are defined for this are:

1. I could explain the interaction between sensors and robots (industrial robots or automated guided vehicles).

2. I could select a sensor system within an industrial environment (e.g. on an assembly line), taking into account the given constraints (what is to be detected, where can the sensor be mounted, what is the coverage radius of the sensors, what resolution is required?)

The first learning objective can be attributed to the "analyzing" level, as the student needs to understand the interaction of multiple components in a system, taking into account the characteristics of each one. With regard to the second learning objective, a classification can be made in the highest level "creating". This is due to the fact that the student has to use different learning contents in order to analyze and evaluate a situation and based on this, implement a system correctly. In order to have the mentioned learning objectives tested with adequate means, the setup of the DGBE and the associated tasks are specified in more detail in the following chapters.

3.3. Game setup

The DGBE represents an industry-related 3D game by recreating typical production engineering situations. At the beginning of the game the player is placed inside a factory embodied as a virtual person (avatar) who can freely explore the environment like it is typical in most first-person games (see Fig. 1). The factory includes different areas such as an assembly station with an industrial robot and an assembly worker, a workbench with sensory equipment, pallets and a forklift for intra-logistic transports. In the first development stage the environment was set to static, so no kinematic simulations or similar effects are realized because they are not mandatory to implement the necessary functions for the exam

tasks. In the following chapters the aim of the game, the game design with the correlating mechanics will be presented in detail.

3.3.1. Aim of the game

In the course of the game, the player is confronted with different tasks in relation to the selection and placement of sensor systems, which he must solve one after the other. Consequently, the aim of the game is to solve these tasks within the given time and attempts. Two tasks were implemented that directly address the learning objectives mentioned in Chapter 3.2. These tasks are:

1. Place a suitable sensor(s) so that the robot stops as soon as the human enters the workspace. Continue to place a sensor so that the robot can grab any size of crate.
2. The forklift shown is to be equipped with sensors so that it can detect distances in the room at the front and back. In addition, appropriate sensors are to be installed at the pallets and at the end of the hall for the automatic booking out of the goods.

For the processing of these tasks the player needs knowledge from the lecture about modern production systems as well as about sensor technology. These sensor technologies are installed in or at the production equipment to extend their functionalities. In addition, the player is given data sheets on the sensors that can be used in the game. The player must identify product-specific properties and interpret them for the solution of the task. These properties include cost, coverage area, sampling rate, and suitability for safety-critical applications. At this point it should be noted that several sensor systems can be considered to solve the task. This results from the fact that the different sensors partly offer the same functionalities, for example a distance can be measured with a lidar sensor as well as with an ultrasonic sensor. The quality of the solution depends on the consideration of the boundary conditions, thus it is necessary to select the most suitable sensor and to insert it into the environment with the correct pose.

3.3.2. Basic game objects

For the development of the game, the Unity 3D engine is used, which allows the implementation of game development packages and assets. The Game Kit Lite [36] serves as a basis, whereby basic game objects, such as characters with motion controllers and information fields, are directly integrated and usable. To further reduce the development efforts for the environment, freely available 3D models of industrial objects from the Unity Asset store are implemented whenever possible. To help the player find relevant areas within the factory, 3D models of exclamation marks are used, shown as action indicators in Fig. 1. The integration of realistic sensors as game objects is ensured using the parts4cad [37] extension, which is also available in the Asset Store. This plugin gives access to a large portfolio of 3D CAD models of real industrial products based on the original manufacturer data. From this, models for a lidar sensor, an ultrasonic sensor, an industrial camera system, an RFID tag and reader are imported. These five sensor systems are the palette from which the player can choose to solve the tasks. The model for the factory was created manually
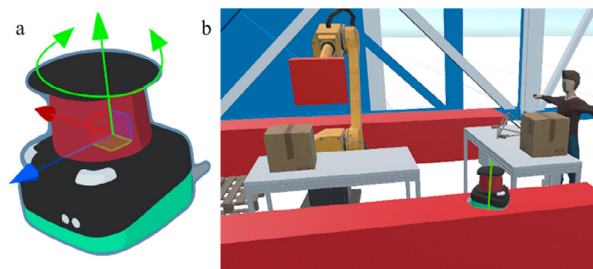

Fig. 2. (a) Coordinate system with the rotational axis of the lidar sensor; (b) Placement and rotation of a sensor system on a cuboid in the game.

because there only were insufficient assets for that. Other objects for which no matching asset can be found, geometric primitives are used. However, in the game this is only necessary for mounting options for the sensor systems which are represented by colored cuboids.

3.3.3. Game mechanics

The most basic functionality in the game is the control of the avatar's movement and view. The movement is controlled via the keyboard with the WASD standard and the view follows the mouse movement.

For the solution of the given tasks, the game mechanic to place and rotate the sensor systems plays the essential role. Since this is no standard functionality in Unity and not available as an asset it is developed as a script which is executed in every frame during the game runtime. The sensor systems can only be placed on the faces of special cuboids marked in red or green, depending on the task. The cuboids belonging to a task are only displayed when the task is active, that means that cuboids of task 1 are hidden as soon as task 2 is enabled. To place a sensor, the view must be directed to these cuboids and a sensor must be selected. This is done by using the number keys, with each sensor system assigned to a fixed number. After that, the sensor is projected into the center of the image following the player view of the player, i.e. the mouse movement. By doing so, the bottom of the sensor will appear to glide above the surface of the cuboid. The player can adjust the placement until he is satisfied with the position and the rotation can be changed using the mouse wheel. The coordinate system of each sensor is defined in the center of gravity of the 3D model, as exemplified in Figure 2 (a). Rotations are only possible around the z-axis, shown in green in the picture. After the player has rotated the sensor by the desired angle, it can be finally inserted into the game environment by clicking the left mouse button. Once inserted, no more changes can be made to the type and pose of the sensor.

Besides that, two different limiters as additional game mechanics are implemented. The first is a time limiter, which restricts the time for answering the questions of the DGBE. This is necessary because the DGBE is only a part of a larger overall exam and it should be prevented that the student spends too much time for the completion of it. During the game, the time left is displayed in the upper right corner as an expiring bar (Fig. 1). After the time has expired, the control is frozen and no further movements can be made. Another limitation is the number of attempts per task, which are visualized by the hearts in the upper left corner. A maximum of seven trials is

provided for each task. An attempt is deducted when a sensor has been finally positioned. If the limit of attempts per task is reached, the processing of the current task is automatically terminated and the next task is started. As with the time limiter, the DGBE is terminated and the controller is frozen when the number of attempts for the last task has elapsed. Since all attempts do not necessarily have to be used up to complete a task, the player can also use key combinations to advance the task or end the exam.

For the purpose of guiding and explanation information zones from Game Kit Lite are implemented. These consist of a sphere and a user interface. This sphere defines the region in which the user interface is shown to the player. An example can be seen at the lower half of Fig.1, here the player is standing inside that information zone of the starting region. Regardless of the respective information zone, the user interface is always defined as a box with text. It will disappear when the player leaves the information zone and pop up again when entering it. Three zones (information content in brackets) are implemented: introduction (movement, limiters), work bench (sensor choice and placement), assembly station (task 1 and 2).

3.3.4. Fulfilment of Gee's principles

With regard to the game described above, it is possible to compare the extent to which Gee's "Principles For Game Based Learning" have been fulfilled. To satisfy the learner empowerment aspect, the player is not given any direct restrictions for solving the tasks. He can navigate through the game world on his own and the effects of his actions have a direct influence on the gameplay. An example of this is the automatic task advancement when all available attempts are used up. An identification with the situation is ensured with the help of the first-person avatar and the immersive game world, which is tailored to the typical surroundings of an engineer.

The area problem solving is addressed in a way that the player is confronted with issues which he was taught about in a lecture and an associated exercise lesson. The fact that solutions of varying quality are possible, means that there is no frustration related to the level of knowledge when working on the task. At the same time, the student's skills can be used to develop a targeted strategy within the DGBE. Furthermore, the limits of time and attempts create an additional challenge. A sufficient and context-based information supply of the player was taken into account with the help of the information zones. Due to the examination character of the game environment, the player cannot be provided with an experimental learning space, since the player's input must inevitably influence the evaluation of his performance.

In relation to the last area "understanding" the link between the game idea and the game elements was made by using realistic 3D models of the sensors as well as of the other environmental elements. Overall, the game shows coverage of Gee's principles, but individual principles are deliberately not implemented due to the nature of the exam.

3.3.5. Evaluation of the solutions

After the completion of the DGBE the results have to be evaluated. As there are infinite possible combinations of sensor selection and pose in the game environment, this is currently planned as a manual process. For this purpose, the data of each student thus the selected sensors are stored digitally with their pose, order of placement and the corresponding task. The corrector of the exam can thus trace the student's solution finding and compare it with the ideal solutions. An exact evaluation scheme for the DGBE has not been developed yet and is part of future developments.

3.3.6. Integration into an examination environment

To conclude, the possibility of integrating the DGBE within a digital exam, which in principle can also be performed from home, is investigated. For this reason, the Safe Exam Browser [9] software is considered and its functionalities are tested for compatibility with a Unity game. The Safe Exam Browser is a software that is specially designed for the secure execution of online exams. It offers the possibility to switch the computer into a so called kiosk mode, in which no other applications can be started. Only the browser with a pre-configured exam environment remains. Within this exam environment, the student solves the designated tasks and can access unlocked content, such as special programs and websites. In order for the DGBE to be integrated into the browser, Unity's WebGL export is exploited. By using this export, the game can be loaded onto a website, which in turn can be integrated into the browser. Using these technologies, a secure testing environment for the DGBE is created. To prevent other types of cheating, e.g. help of another person, a webcam and microphone monitoring could be implemented as shown by Atoum et al. [38].

4. Evaluation

After the completion of the MVP of the game an evaluation was carried out in cooperation with the Center for Teaching and Learning of the TUHH. The goals of the evaluation are to gain insights about the didactic aspects of the games as well as to gather feedback for the further software development. From a didactic point of view the suitability of the game for exams, the fulfillment of the learning goals and the general acceptance of DGBE are essential. In terms of the software development questions and comments about the perception of the game experience and comprehensibility are important. For this purpose, a questionnaire with five different sections, each containing several questions, was created. Depending on the questions the answer possibilities could be a grading from "fully agree" to "do not agree at all", a "yes" or "no" answer, a selection of given options or a straight answer. The sections of the questionnaire in chronological order are:

- Conduct of the examination
- Learning objectives
- Open comments on the e-examination
- General questions about e-examination
- Evaluation of the teaching innovation

The fourth and fifth section of the survey addressed topics about university internal processes and are therefore not discussed in this paper due to lack of relevance. In total 7 participants took part in the survey, and these were either postgraduate engineering students or research associates in the

production technology field. The participant group of students from higher semesters was deliberately chosen because of their knowledge in this subject area. The scientific staff are experts in this field because of their professional activities. This approach ensures that all tasks can be solved correctly.

At the beginning of the evaluation procedure each participant was informed about the background of the DGBE as described in chapter 3.1. Subsequently, the DGBE was conducted under real examination conditions including time and attempt limits without any further external instructions. After finishing the DGBE the results were discussed and the survey was filled in by the participant.

In the first section of the evaluation four questions aimed at the sufficient information provision, the understanding of the procedure and technical functions of the game. More specifically, the provision of information and general introduction before the start of the audit, which comprised the first two questions, was rated with a distribution of 4 ("fully agree") to 3 ("rather agree") in both survey items. The understanding of the tasks as well as the technical functions of the game was evaluated in two questions with a consistent rate of 6 times "fully agree" and 1 time "rather agree". It can be concluded that the information zones installed in the game and the explanations about the game mechanics are sufficient for an understanding. Furthermore, it was asked if the learned content could be adequately tested by the type of assignment. All participants answered either with "fully agree" (5) or "rather agree" (2) to these questions. From this it can be deduced, that basic suitability for querying the contents of the lecture can be determined. When asked if the game was easy to use, two participants answered "fully agree," 4 "rather agree," and one "rather disagree." This can be attributed to the first version development stage of the game, as no optimization loops for the operation have been carried out yet. Thus the control of the game will be optimized within the next development iteration.

The next section of the evaluation asks to what extent the DGBE addresses the learning objectives presented in chapter 3.2. With regard to the first learning objective, 4 participants answered with "fully agree" and 3 with "rather agree". Whereas the second learning objective was evaluated by 5 participants with "fully agree" and by 2 with "rather agree". As a result, the set learning objectives could be adequately tested with the help of the game. The slightly worse result with regard to the first learning objective can be explained by the fact that the interactions of systems are only represented to a limited extent by the static virtual environment. This could be remedied by additional dynamic content which will be addressed in future functionalities.

In the third section open comments as well as suggestions for improving were collected. To sum it up, the game-based approach in particular was seen as positive and motivating. Another aspect mentioned was the practical and realistic approach to the DGBE. Points that were brought up as potential for improvement were, the still jerky character control and the design of the sensor mounting points.

5. Discussion & Future Work

This paper presented a DGBE environment which was fully implemented with Unity 3D leveraging the didactic as well as software development approaches presented in Chapter 2. Gee's principles for a good DGBL have been realized as far as possible within the game. Furthermore, different gamification elements were implemented within the environment to ensure a playful feeling despite the examination situation. The presented version of the game represents a first completed development stage, which so far includes two tasks on the topic of sensor systems in Industry 4.0. Beyond that, the integration within a secure examination environment was exemplified with the Safe Exam Browser, which opens up possibilities for integration in online examinations. With the help of the evaluation, first conclusions about the suitability of this form of assessment for testing complex issues addressing higher-order learning objectives could be made. Despite the low number of participants in the study, which is due to the lower availability of students during online semesters, the conclusion can be drawn that the use of the DGBE is promising. In conclusion, the DGBE presented here offers great advantages over traditional teaching and testing methods, especially for the university education of engineers. It allows the student to become immersed in a particular situation in which he is able to show skills that are relevant for today's working world. However, there are still contents that are more efficiently tested in traditional exam formats, because the development efforts for virtual environment are high and not worthwhile for basic contents which address the first levels of the presented learning taxonomy. Therefore, the DGBE will not be used to replace a whole exam but to supplement it for the appropriate contents.

Based on the software development approach and the MVP presented in this paper, the future work will focus on creating a second version implementing the feedback of the evaluation as well as advanced functionalities. First of all, the motion control is further refined and the geometric primitives are replaced by more graphic models. Subsequently, the game environment will be scaled up in different ways. With the current setup centered on the robot assembly station more questions will be elaborated to extend the task variety. Moreover the factory layout has still room for further assets to be placed. The lack of freely available assets for factory environments will be countered by the use and import of 3D CAD models of industrial components. This ensures easy expansion of the game environment and lays the foundation for additional task types. In addition to the implementation of further tasks, the refinement of the game mechanics is a key point. As dynamic interaction possibilities can directly show the consequences of the player's actions in the game resulting in a better learning outcome this will be part of future developments. An example of this is the realization of a robot motion after attaching a sensor system to it.To ensure the practical effectiveness of the approach and to gain more feedback on the above mentioned game extensions there is a need for a more detailed study with a higher number of participants. Therefore, the second version will be tested through a mandatory online exercise session with an advanced study in the next lecture cycle. By doing so, an estimated

number of 50 participants will be guaranteed and more profound results will be obtained. This approach will assure that the additional functionalities will continue to contribute to the conveyance of the learning objectives and respond to the needs of the student. In addition, the use of the Safe Exam Browser can be included in this study to test its use in an online exam. If this study is successfully completed, it is envisioned that it will be incorporated into the existing exam.

CRediT author statement

Koch: Conceptualization, Methodology, Software, Validation, Investigation, Visualization, Writing – Original & Draft & Review & Editing. Gomse: Supervision, Funding acquisition, Writing - Review & Editing, Project administration. Schüppstuhl: Resources, Supervision. ZLL: Data Curation, Formal analysis, Funding acquisition.

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References

[1] M.J. Callaghan, K. McCusker, J.L. Losada, J. Harkin, S. Wilson, Using Game-Based Learning in Virtual Worlds to Teach Electronic and Electrical Engineering, IEEE Trans. Ind. Inf. 9 (2013) 575–584. https://doi.org/10.1109/TII.2012.2221133.

[2] M. Prensky, Digital game-based learning, McGraw-Hill, New York, 2001.

[3] D. Wang, Gamified learning through unity 3D in visualizing environments, Neural Comput & Applic 29 (2018) 1399–1404. https://doi.org/10.1007/s00521-017-2928-5.

[4] J. Hamari, D.J. Shernoff, E. Rowe, B. Coller, J. Asbell-Clarke, T. Edwards, Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning, Computers in Human Behavior 54 (2016) 170–179. https://doi.org/10.1016/j.chb.2015.07.045.

[5] D. Eseryel, V. Law, D. Ifenthaler, Ge, Xun: Miller, Raymond, An Investigation of the Interrelationships between Motivation, Engagement, and Complex Problem Solving in Game-based Learning, Educational Technology & Society (2014) 42–53.

[6] K.J.M. Kiili, K. Devlin, A. Perttula, P. Tuomi, A. Lindstedt, Using video games to combine learning and assessment in mathematics education, IJSG 2 (2015). https://doi.org/10.17083/ijsg.v2i4.98.

[7] K. DiCerbo, Game-Based Assessment of Persistence, Journal of Educational Technology & Society (2014) 17–28.

[8] J. Crawford, K. Butler-Henderson, J. Rudolph, B. Malkawi, M. Glowatz, R. Burton, P. Magni, S. Lam, COVID-19: 20 countries' higher education intra-period digital pedagogy responses, JALT 3 (2020) 9–28. https://doi.org/10.37074/jalt.2020.3.1.7.

[9] Safe Exam Browser, About Overview, 2021. https://safeexambrowser.org/about_overview_en.html (accessed 16 January 2021).

[10] Speed Exam, Your Online Testing Partner, 2021. https://www.speedexam.net/ (accessed 16 January 2021).

[11] A. Tatnall, M. Webb (Eds.), Tomorrow's learning: involving everyone: Learning with and about technologies and computing 11th IFIP TC 3 World Conference on Computers in Education, WCCE 2017, Dublin, Ireland, July 3-6, 2017 revised selected papers, Springer, Cham, 2017.

[12] R. Al-Azawi, F. Al-Faliti, M. Al-Blushi, Educational Gamification Vs. Game Based Learning: Comparative Study, IJIMT (2016) 131–136. https://doi.org/10.18178/ijimt.2016.7.4.659.

[13] T.E. Coleman, A.G. Money, Student-centred digital game–based learning: a conceptual framework and survey of the state of the art, High Educ 79 (2020) 415–457. https://doi.org/10.1007/s10734-019-00417-0.

[14] J.P. Gee, Good video games + good learning: Collected essays on video games, learning, and literacy, Lang, New York, 2007.

[15] T. Anastasiadis, G. Lampropoulos, K. Siakas, Digital Game-based Learning and Serious Games in Education, IJASRE 4 (2018) 139–144. https://doi.org/10.31695/IJASRE.2018.33016.

[16] S. Kauffeld, J. Othmer, Handbuch Innovative Lehre, Springer Fachmedien Wiesbaden, Wiesbaden, 2019.

[17] J. Hautala, R. Heikkilä, L. Nieminen, V. Rantanen, J.-M. Latvala, U. Richardson, Identification of Reading Difficulties by a Digital Game-Based Assessment Technology, Journal of Educational Computing Research 58 (2020) 1003–1028. https://doi.org/10.1177/0735633120905309.

[18] J.S. Groff, The potentials of game-based environments for integrated, immersive learning data, Eur J Educ 53 (2018) 188–201. https://doi.org/10.1111/ejed.12270.

[19] S. Deterding, D. Dixon, R. Khaled, L. Nacke, From game design elements to gamefulness, in: Proceedings of the 15th International Academic MindTrek Conference Envisioning Future Media Environments, Tampere, Finland, ACM, New York, NY, 2011, p. 9.

[20] S. Stieglitz, C. Lattemann, S. Robra-Bissantz, R. Zarnekow, T. Brockmann, Gamification, Springer International Publishing, Cham, 2017.

[21] O. Goethe, Gamification Mindset, Springer International Publishing, Cham, 2019.

[22] R. Hunicke, M. Leblanc, R. Zubek, MDA: A Formal Approach to Game Design and Game Research, AAAI Workshop - Technical Report 1 (2004).

[23] U. Ruhi, Level Up Your Strategy: Towards a Descriptive Framework for Meaningful Enterprise Gamification, Technology Innovation Management Review 5 (2015) 5–16. https://doi.org/10.22215/timreview/918.

[24] K.M. Kapp, The gamification of learning and instruction: Game-based methods and strategies for training and education, Pfeiffer, San Francisco, Calif., 2012.

[25] L.W. Anderson (Ed.), A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives, Longman, New York, 2009.

[26] I. Sommerville, Software Engineering, tenth., aktualisierte Auflage, Pearson, Hallbergmoos, 2018.

[27] J.N. Rosenfield Boeira, Lean Game Development, Apress, Berkeley, CA, 2017.

[28] J. Arnowitz, M. Arent, N. Berger, Effective prototyping for software makers, Morgan Kaufmann/Elsevier, Amsterdam, 2007.

[29] A. Matallaoui, P. Herzig, R. Zarnekow, Model-Driven Serious Game Development Integration of the Gamification Modeling Language GaML with Unity, in: 48th Hawaii International Conference on System Sciences (HICSS), 2015, HI, USA, IEEE, Piscataway, NJ, 2015, pp. 643–651.

[30] V. Schiller, M. Liebscher, M. Brade, Nutzerzentrierte Entwicklung einer Game-based Learning Anwendung für Unity, Gesellschaft für Informatik e.V, 2020.

[31] V.T. Nguyen, T. Dang, Setting up Virtual Reality and Augmented Reality Learning Environment in Unity, in: Adjunct proceedings of the 2017 IEEE International Symposium on Mixed and Augmented Reality, Nantes, France, IEEE, Piscataway, NJ, 2017, pp. 315–320.

[32] Unity, Echtzeitlösungen, endlose Möglichkeiten. https://unity.com/de/solutions (accessed 30 December 2020).

[33] S. Blackman, Beginning 3D game development with Unity: The world's most widely used multi-platform game engine, Apress; Distributed to the book trade by Springer Science + Business Media, New York NY, 2011.

[34] C. Seifert, J. Wislaug (Eds.), Spiele entwickeln mit Unity 5: 2D- und 3D-Games mit Unity und C# für Desktop, Web & Mobile, 3rd ed., Hanser, München, 2017.

[35] Unity, Unity Asset Store, 2021. https://assetstore.unity.com/ (accessed 18 January 2021).

[36] Unity, 3D Game Kit Lite. https://learn.unity.com/project/3d-game-kit-lite (accessed 30 December 2020).

[37] game4automation, parts4cad - millions of industrial 3D components for Unity, 2021. https://game4automation.com/produkte/unity-parts4cad (accessed 23 January 2021).

[38] Y. Atoum, L. Chen, A.X. Liu, S.D.H. Hsu, X. Liu, Automated Online Exam Proctoring, IEEE Trans. Multimedia 19 (2017) 1609–1624. https://doi.org/10.1109/TMM.2017.26560