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Design of an adaptable serious game for multiple stakeholder perspectives

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Abstract

The world is becoming increasingly digital. People have become used to learning and interacting with the world around them through technology, accelerated even further by the Covid-19 pandemic. This is especially relevant to the generation currently entering education systems and the workforce. Considering digital aids and methods of learning are important for future learning. The increasing online learning needs open the case for integrating digital learning aspects such as serious gaming within education and training systems. Learning factories fall amongst the education and training systems that can benefit from integration with digital learning extensions. Digital capabilities such as digital twins and models further enable the exploration of integrating digital serious games as an extension of learning factories. Since learning factories are meant for a range of different learning, training, and research purposes, such serious games need to be adaptable across stakeholder perspectives to maximize the value gained from the time and cost invested into such design and development. Research into the development of adaptive serious games for multiple stakeholder perspectives must first determine whether such development can be developed that reaches the objectives set for different included stakeholder perspectives. The purpose of this research is to investigate this at the hand of the practical development of a digital adaptive serious game for stakeholder perspectives.

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1. Introduction

Globalization of digital technology is accelerating. The Covid-19 pandemic has further hastened how accustomed people have become to engaging with the environment and learning through technology. This is particularly true of the generation now enrolling in educational programs and entering the workforce. They are referred to as "digital natives" by Prensky [1] since they were raised on digital technology and are hence fluent in its language. Future learning will benefit from taking into account digital tools and methodologies.

Incorporating digital learning elements like serious gaming into education and training systems is now possible and desired due to the growing demand for online learning [2], [3]. The incorporation of digital learning extensions can be beneficial for education and training systems such as learning factories. Virtual learning factories enabling higher scalability and mobility to learning factory approaches [3] through lower resource consumption are being investigated more and more. These approaches along with digital tools like digital twins and models make it possible to explore the integration of digital serious games as an addition to learning factories.

Since learning factories are intended for a variety of teaching, training, and research goals [3], such serious games must be adaptable across stakeholder perspectives to optimize the return on the time and money invested in such design and development.

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Research into the creation of adaptable serious games for multiple stakeholder perspectives must first ascertain whether such development is capable of producing products that meet the objectives of multiple stakeholder perspectives included. This research investigated this through the practical construction of a digital adaptable serious game for stakeholder perspectives.

2. Theoretical background

2.1. Serious games

Serious games have a variety of definitions throughout literature. They are described as "... a game in which education (in its various forms) is the primary goal, rather than entertainment." by Djaouti, Alvarez and Jessel [4]. This definition, however, neglects serious games used for non-educational goals like marketing, piquing attention, creating excitement, etc. The more encompassing definition offered by Michael and Chen [5] is that "Serious games are games used for purposes other than mere entertainment." However, it doesn't place enough attention on how serious games harness the benefits of games and game design to improve other aspects of life. Susi and Johannesson's [6] definition, "The application of gaming technology, process, and design to the solution of problems faced by businesses and other organizations. Serious games promote the transfer and cross-fertilization of game development knowledge and techniques in traditionally non-game markets such as training, product design, sales, marketing, etc." fills this gap. Further, this definition is a crucial place to start for serious game designers since it highlights important aspects that can help avoid frequent flaws of serious games, such as the misalignment of goals and design approaches and the lack of understanding of purposeful game design [7].

2.2. Serious games and learning factories

Both learning factories and serious games provide the opportunity for the contextualization of theoretical knowledge in a practical environment, either physical or digital. This allows participants to expand their theoretical and practical knowledge through experiential learning. Serious games further enable players to test their skills and explore processes in a dynamic environment without fear of failure or causing damage [8]. They can experience the consequences of their actions and learn from them in a safe environment with instant feedback. Several studies have investigated serious game implementation in learning factories and found positive results [9]–[11].

While multi-player serious games have been studied, little research has been done on serious games that can be adapted for multiple stakeholder perspectives. Adaptability across stakeholder perspectives has however been highlighted as a desirable trait by some study participants as well as proposed by other studies [9], [12]–[14] as potential future work.

The advantage of adaptability across stakeholders is that it allows for the use of the same core game elements while still engaging various stakeholders according to their knowledge level and the related desired outcomes for a stakeholder group.

2.3. Training Factory Industry 4.0

The fischertechnik Training Factory Industry 4.0 is a physical simulation model created for education related to Industry 4.0 concepts and applications [15]. The model consists of a production line with a delivery and pickup station with an NFC (near field communication) reader, a vacuum gripper robot, a high-bay warehouse, a multi-processing station including a kiln and milling station, a sorting line with colour detection, and a sensor station with a camera.

3. Design of adaptable serious game for multiple stakeholder perspectives

3.1. Research approach

The research approach used to determine whether adaptable serious games may be created for multiple stakeholders combined a pragmatic mindset with an applied research approach. Two versions of the game, each targeted at a different stakeholder group, were developed from an existing 3D model of the fischertechnik Training Factory Industry 4.0. The first group consisted of high school students from South Africa, ranging in age from 15 to 17. The group's serious game goals included providing an entertaining and engaging introduction to the discipline of industrial engineering. The second group consisted of South African industrial engineering students. The goal for this group was to be able to apply their theoretical knowledge in a practical environment experience.

3.2. Game design

As part of the design of the serious game for multiple stakeholder perspectives, a set of conceptual guidelines were put together as seen below in Figure 1. This was used together with select functionalities from the architecture for bidirectional learning games to guide the design of the game. The functionalities used from the architecture for bidirectional learning games include context management, stakeholder management, requirements management, evaluation, construction management and configuration management. As part of the context management and requirements management, the South African school curriculum along with Stellenbosch University's Industrial Engineering curriculum was consulted to understand the prior knowledge of stakeholders and their requirements. The Institute of Industrial and Systems Engineering's Body of Knowledge was also consulted to identify typical industrial engineering tasks and knowledge for possible game content. Process flow mapping was applied to the physical factory to identify areas where concepts or game functionalities can be introduced. As part of requirements management, common serious games outcomes [16] were consulted to determine the objectives for each stakeholder group.

Design function	Guiding questions	Aspects for consideration
1. Stakeholder inclusion decision-making	• Will the stakeholder benefit from a serious game approach? • Would the stakeholder be willing to participate in a serious game? • Are there any stakeholder relationships that could benefit from integration in a serious game?	• Application scenario • Context • Stakeholder influence • Stakeholder relationships
2. Defining objectives and desired outcomes	• What are the desired outcomes of the serious game for each stakeholder? • Are there any underlying outcomes and objectives for each stakeholder? • What are the main serious game related objectives of each stakeholder? • Are there any secondary serious game related objectives for each stakeholder?	• Project objectives per stakeholder • Common desired objectives of serious games • Prioritization of objectives and outcomes
3. Perspective design	• What are the prior knowledge levels of stakeholders? • What are the prior experience levels of stakeholders? • What is the contextual scenario related to the different stakeholders and their objectives? • What would a serious game setting look like that is suitable for stakeholder knowledge and experience levels? • What game functionalities can be used to address stakeholder objectives?	• Stakeholder knowledge and experience • Context • Technical fulfilment of objectives • Level of visualization and detail needed
4. Multi-perspective integration	• Are there overlapping objectives and functionalities for some stakeholders? • Are there conflicting objectives and functionalities for some stakeholders? • Is it necessary to incorporate user-type switching for access to different functionalities?	• Game setting • Prioritized objectives • Overlaps and conflicts • Integration of game functionalities • User-type switching

Figure 1. Conceptual guidelines for serious games for multiple stakeholder perspectives

High school students have limited prior knowledge and exposure to industrial engineering and processes. Enjoyment and knowledge improvement were the desired outcomes of the serious game for high school students. Industrial engineering students have prior theoretical knowledge of processes and industrial engineering. They require higher practical experience, contextualization, and the opportunity to experience the impact of applying their knowledge in a safe environment with fast feedback. The desired outcomes for students studying industrial engineering included increased knowledge, self-efficacy, concept retention, and intrinsic motivation.

3.3. Game development

The game was created using the Unity game engine and was written in C#. The initial development included constructing game feature "building blocks" which can be combined and implemented to form the desired game functionalities. These building blocks included player movement, camera following, dialogue management, machine movement cutscenes, object interaction and non-player character (NPC) interaction.

The building blocks were employed after development to configure the shared and unique functionality for the two game versions. The basic player experience of the factory was created using a combination of the player movement, camera following, and interaction elements. The dialogue system, machine movement cutscenes, and interaction with NPCs were all combined to create a factory tour. A questing system and four minigames were also produced along with information pop-ups for the various machines.

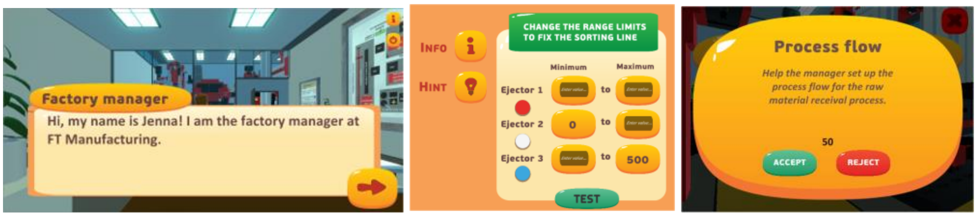

Figure 2. Excerpts from serious game - Dialogue system, sorting line minigame, questing system

The final game flow for high school students starts off with the factory manager NPC taking the player through each station in the factory. An animation of the station process is shown at each station along with a brief explanation of the station and the role that industrial engineers play in the process. After the tour, the player is free to explore the factory, where they can interact with certain machines to learn more about how they work, rewatch the animation or learn about industrial engineering in the context of the machine. There are also one minigame hidden in the game, the sorting line minigame. The sorting line minigame takes the player through the process of solving a problem where the sorting line sorts some products into the wrong bins. The player is encouraged to play around with the light sensor barrier values to change the way different colored products are sorted. The player can test their input and is immediately presented with feedback in the form of an animation showing how products are sorted due to their barrier value inputs.

The final flow for the industrial engineering students also starts with the factory tour, however without the explanation of industrial engineering. The game takes a more active than exploratory path after the tour. After the tour the player is asked to engage with the other factory employee NPCs to find a set of quests to be completed to finish the game. The sorting line minigame is included as a quest that can be obtained by talking to a specific NPC. An ordering minigame, process flow minigame and production strategy minigame were added as additional quests. The player then explores the factory until they have completed all the quests, after which the game ends.

4. Data collection

Demonstration sessions with two distinct stakeholder groups, high school students and industrial engineering students, are used to validate if a serious game can be designed for multiple stakeholder perspectives. Their opinions were gathered through questionnaires and examined to draw a conclusion. The questionnaires were semi-structured with statement questions on a 5-point Likert scale in the first section and opinion-based questions in the second section. To glean a deeper understanding of the student's experience, yes/no questions were combined with open-ended questions in the second section.

A group of 65 grade 9 students from a private school participated in the demonstration high school student validation study. The game was provided to them via the researcher's laptop and projected on a screen rather than having each student play individually due to limitations on the available infrastructure, allowing the complete group to watch the game. A portion of the group was requested to participate in the game's actual interactivity, which involved moving the character and interacting with the equipment and NPCs. In addition, suggestions from the entire group were sought during the light sensor minigame. 64 students completed the research feedback questionnaire after the demonstration, of which 15 were eliminated from the study due to incomplete responses or improper comments on the feedback form. The final data consisted of 49 completed questionnaires.

A total of 12 students from the industrial engineering department of a South-African university participated in the industrial engineering validation study. Each of these students individually played the game and completed the questionnaire. From these, 4 were eliminated from the study due to incomplete responses.

5. Results

The first part of the high school student questionnaire consisted of statement questions. The students were asked to rate their degree of understanding of industrial engineering before (Question 1) and after (Question 4) the game presentation. The results from these questions were compared using a paired t-test to determine whether the game demonstration had significantly improved the students' grasp of industrial engineering. The dependent, two-sample nature of the data led to the selection of the paired t-test. The test was performed using $\alpha = 0.05$. The test statistic (6.64694050513) is larger than the critical value for a one-tailed paired t-test (1.677224196). The P-value (1.2795E-08) is also much smaller than the α-value used. This results in the right-tailed hypothesis: H_0 = Question 4 ≤ Question 1; H_1 = Question 4 > Question 1 being rejected. Resultantly, the students' understanding of industrial engineering was improved significantly by the game demonstration.

The general statement questions, results shown in Figure 3, revealed that the students found the game flow easy to follow (mean 3.71). They also enjoyed the game (mean 3.82) and learning about industrial engineering in a game format (mean 3.96). The students felt that their understanding of industrial engineering was improved by the game (mean 3.94).

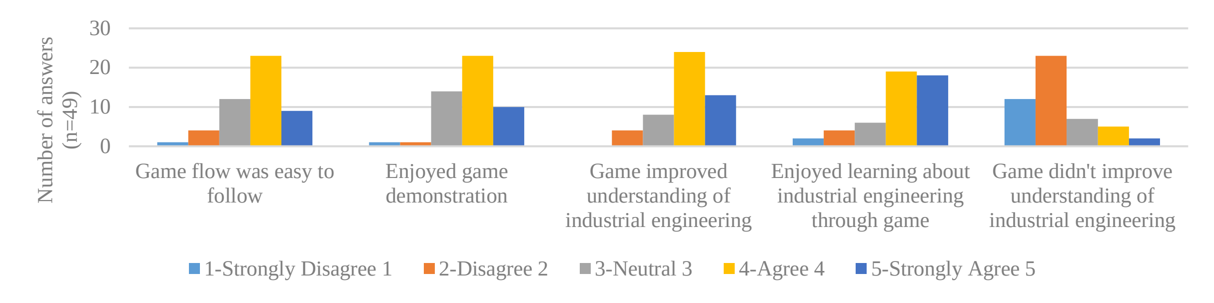

Figure 3. Results of general questions - High school students

The second part of the questionnaire consisted of open-ended questions, analyzed using thematic analysis. When asked if there were specific parts of the game that they liked, 80% of the 49 students agreed. The game's concept and design, the minigame, interactivity, graphics and machine animations were mentioned as aspects that they liked. Only 22% of students indicated that there is a particular part of the game that they disliked. The majority of these disliked the slow and lagging animation. However, this was due to the Wi-Fi connection with the projector during the demonstration, not the game itself. Problems navigating the factory's layout, experiencing the factory as small, the player character's slow turning time, and trouble following the factory manager during the tour were also mentioned. One student suggested making the factory manager more visible by adding a glowing trail.

In reaction to being asked whether there are things that should be added to make the game more enjoyable, 63% said yes. Suggestions included enhanced graphics and animations as well as even more interactivity, a different voice for the manufacturing manager, more upbeat music, and adding some competitive aspects to the game. Only 10% of the students indicated that there were things that should be removed from the game to make it more enjoyable. Suggestions included removing the voice of the factory manager, reducing the amount of explanation, and investigating some difficulty to keep up with too much going on at once.

The general statement questions for the industrial engineering students, results shown in Figure 4, revealed that the students felt the game improved their understanding of applying the included industrial engineering concepts (mean 3.88). They also enjoyed the game (mean 4.25) and found it easy to navigate (mean 3.75). Further, they indicated they enjoyed applying industrial engineering concepts in a game format (mean 4.75) and would like to learn about more of their study content in a game format (mean 4.5). The students felt that their understanding of industrial engineering was improved by the game (mean 3.94).

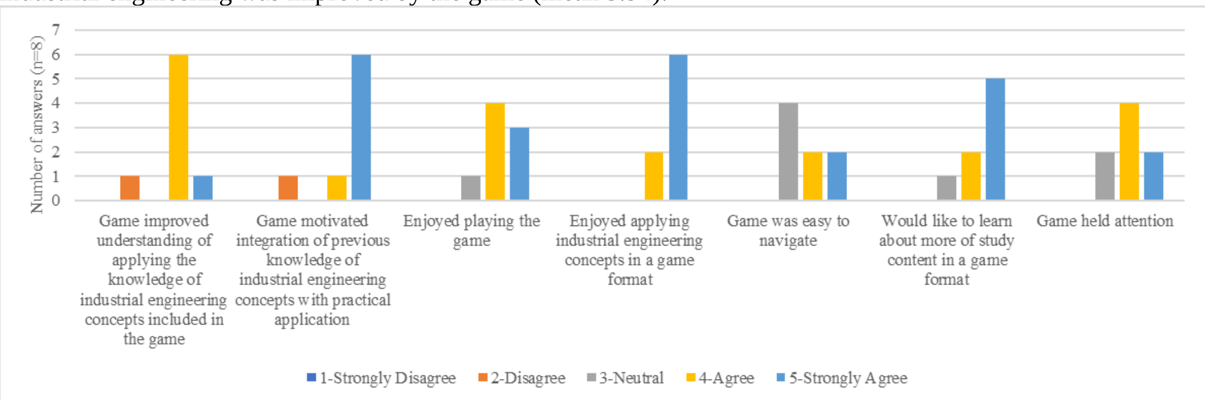

Figure 4. Results of general questions - Industrial engineering students

In terms of the open-ended questions, 100% of the industrial engineering students indicated there were parts of the game they enjoyed. The students indicated the enjoyed the fun and satisfaction of completing quests correctly, easy character movement and the smoothness of the game. They also appreciated how the game helped with learning and understanding industrial engineering concepts, the interactivity in terms of quests and machine animations, the visualization of knowledge and exploring a factory setup in a 3D gaming environment. Excitement about the potential practical applications of the game for training students and workers in the industry was also expressed. 37% of the students mentioned there were parts they disliked. Animation issues and game glitches, user interface spacing issues in the process flow minigame, difficulty interacting with machines, and difficulty figuring out what to do next were mentioned.

When asked if they think anything should be added to the game to make it more enjoyable, 62% agreed. They suggested expanding the game content with more quests, multistage quests and machine maintenance interactions as well as improving the user interface and game mechanics for better user experience. None of the students indicated that there were any things in the game that should be removed to make the game more enjoyable.

In conclusion, the results from both the high school student and industrial engineering student questionnaires point to the game meeting the desired outcomes for both stakeholders. As a prototype, the game version was successful and positively perceived by both stakeholder groups. Several insightful recommendations for future improvements were also collected.

6. Conclusion and future work

The game met the desired outcomes for both high school students and industrial engineering students. Resultantly, adaptable serious games for multiple stakeholder perspectives are capable of meeting the objectives for the multiple stakeholder perspectives included. Conscious consideration of the needs of each stakeholder and how they relate to each other translated into game functionality design should be explored further in the serious game design space.

Suggestions for future work include expanding the current game and implementing similar game functionalities with 3D models of learning factories. The two existing stakeholder groups' game content could be expanded, and versions of the game for new stakeholder groups like managers or factory workers could be added. Investigation can also be done into a user-friendly interface for users such as lecturers and training facilitators to be able to add content to the game without requiring extensive programming or game development knowledge. Further, introducing bidirectional learning to the game can also be beneficial to explore.

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