Fostering Critical Thinking by a Gamification Approach

Dictus Christian[1], Tiemann Rüdiger[2]

[1, 2] Humboldt-University of Berlin, Germany

Abstract

The advancing digitization of all areas of society requires students to master a new set of skills – the 21st century skills - which enables them to understand current problems and participate in scientific and social discourses. Two of these skills are critical thinking and problem solving [1]. Although the requirement to foster these skills is already known, it still lacks adequate tools to do so. To fill a part of this gap, we are developing a modern, game-oriented, digital learning environment ("MINT-Town"). Unfortunately, current problems tend to be very complex and dynamic, which makes it hard to hold students' motivation on a sufficient level. Therefore, we integrated gamification elements (e.g., quests, dialogs, avatars) to motivate and engage students to work on complex problems for a longer period. The potential of gamification elements to increase student's motivation [2, 3] and learning outcomes [3, 4] has already been shown in several studies. Our game consists of two parts: 1) the tutorial, and 2) the chemical part. In part one, the player is confronted with a general STEM oriented problem situation; he has time to learn the basic controls of the game and several critical thinking subskills [5] while the questline leads him through the problem-solving process [6]. A prototype of this part is already done and has been validated by an expert rating using an online questionnaire. The experts (doctoral students of STEM education) clearly identified the implemented problem-solving steps and the promoted critical thinking subskills; they were highly motivated by the embedded gamification elements. Based on the feedback we are going to improve the first part and will develop the second part of the game. In a last step, we will evaluate the whole game in a quantitative study on 10th grade students.

Keywords: *critical thinking, educational game, gamification, motivation, problem solving, student engagement,*

1. Introduction

When smartphones became commonly used gadgets, and virtual reality was no longer limited to the gaming industry, advancing digitization opened up new opportunities in many areas, but also revealed the complexity of today's problems. To prepare our students to face these challenges we need to teach them a new set of skills: the 21st century skills.

Two of these skills [1] - critical thinking and problem solving - are well known concepts, and a lot of research has already been made regarding their assessment. But, it still lacks modern tools to foster these skills in the context of STEM, and especially in chemistry education.

Due to the complexity of the problem situations another difficulty is to hold student's motivation on a sufficient level, which can be achieved using gamification elements. They have the potential to increase student's motivation [2, 3] and learning outcomes [3, 4].

To close a part of this gap, we aim to develop a modern game-oriented learning environment – MINT-Town - which should be used to foster critical thinking skills of 10th grade students in the context of STEM and chemistry education. Using gamification elements, we aim to motivate the students and guide their learning process.

2. Instruments and Methods

2.1 Development of MINT-Town

We developed our digital learning environment - MINT-Town – partly based on the model for designed digital learning environments [7], which is subdivided into the following five steps: (1) Analysis, (2) Design, (3) Development, (4) Quality Assurance, (5) Implementation & Evaluation.

The development process can be described as follows: (1) We used a role-playing game as an instrument to represent a complex problem situation and foster critical thinking skills along the problem-solving phases, which gave us the opportunity to easily embed gamification elements (Fig. 1) and hold student's motivation on a sufficient level; (2) Taking into account that these skills should be

fostered in different STEM educational contexts, we aimed to make it expandable and therefore split it into the general STEM oriented and the chemical part; (3) We developed the STEM oriented part – the MINT-Town Tutorial - using the software “RPG Maker MV v.1.6.2”, as well as the plugins “CoreEngine” and “MessageCore” by “Yanfly”, which enabled larger screen resolutions and more options to customize the message boxes; (4) To ensure the quality of the prototype the first part was validated by an expert rating (see 2.2).

Fig.1. The players explore the digital learning environment with their avatar (left); are guided through the problem-solving steps via quests (middle); and collect useful information via dialogs with NPCs (non-player characters) to find a solution (right).

2.2 Expert rating of the MINT-Town Tutorial

We asked 6 doctoral students of chemistry education to play the prototype of the MINT-Town Tutorial and provide feedback regarding the quality of the digital learning environment. The experts received an online questionnaire which consisted of 3 different parts: (1) game progress, (2) addressed skills & motivation, and (3) open feedback. In the first part, we asked them about their playing time and game progress. In the second part, we used 5-point Likert scales to find out which problem solving phases (based on [6]) and critical thinking skills ([5]) are addressed by the game and which gamification elements were motivating to the experts. In the third part, we asked the experts for open feedback to evaluate the necessity and gather ideas for further improvement.

3. Results

3.1 Game Progress

The experts spent an average time of three quarters of an hour playing; at least 5 of them were able to finish the part completely. The sixth expert managed to collect all information, but he stopped playing after 35 minutes, because he was not able to finish the problem characterization step. In the open feedback he suggested that some graduated learning aids should be implemented to support this important step. Two other experts said that collecting information was partly difficult and took a lot of time, because it was unclear which information was missing, and where it could be found. Although the experts described the quest- and the storyline as “logical” and “well designed” they proposed to implement a quest log as well as separated chapters providing visual feedback on the actual game progress.

3.2 Problem solving phases

Most experts recognized the first three problem solving phases we implemented into the game (based on [6]): (1) Identify and characterize the problem, (2) Represent the problem, (3) Solve the problem. They especially identified the phases 1 and 3 with mainly strong agreement.

3.3 Critical Thinking Skills

We asked the experts to confirm the application of several critical thinking skills (and subskills) in the first part of MINT-Town (Table 1): Especially the basic critical thinking skills (1.-3.) [5], the “deductive thinking” skill (6.) and the “follow problem solving steps” subskill (13.) are highly addressed by the game.

Table 1. Selection of critical thinking skills [5], whose application was confirmed by the experts in the first part of MINT-Town, median, range.

Critical thinking skill	Level of consent (5-point Likert-scale*)	
	Median	Range (min-max)
1. Focus on a question		

Identify a question/problem-solving task	5	1 (4-5)
Formulate a question/problem-solving task	4	3 (1-4)
2. Analyze arguments		
Identify conclusions	4	4 (1-5)
Identify reasons or premises	5	1 (4-5)
Identify simple assumptions	5	4 (1-5)
See the structure of an argument	4	4 (1-5)
3. Ask and answer clarification/challenge questions		
Answer clarification and/or challenge questions	4	2 (2-4)
5. Observe, and judge observations		
Observe	4	3 (2-5)
6. Deduce and judge deduction		
Derive logical, conditional or causal relationships	5	3 (2-5)
Judge logical, conditional or causal relationships	5	4 (1-5)
8. Make and judge value judgements		
Make value judgements	4	4 (1-5)
10. Attribute unstated assumptions		
Recognize underlying assumptions	4	4 (1-5)
Name underlying assumptions	4	4 (1-5)
11. Suppositional thinking	4	4 (1-5)
12. Integrate the dispositions and other abilities in making and defending a decision		
Make decisions based on dispositions and learned skills	4	3 (2-5)
13. Proceed in an orderly manner appropriate to the situation		
Follow problem solving steps	5	3 (2-5)
14. Be sensitive to feelings, level of knowledge, and degree of sophistication of others	4	4 (1-5)

* 1 – it does not apply, 5 – it applies

3.4 Motivational gamification elements

We determined that all gamification elements we used in MINT-Town - part 1 to motivate the players, successfully worked with most of the experts (Table 2). The greatest agreement among the experts regarding the motivational effects was on the “use of key items”, “interaction with NPCs” and “storytelling”.

4. Discussion

We successfully developed a first prototype of the digital learning environment “MINT-Town Tutorial” – the STEM oriented part of our game MINT-Town - and validated it by a first qualitative expert rating via an online questionnaire. Although the game already met many of our aimed criteria it must go through a further improvement circle.

The data of the questionnaire suggests that the game is very motivating to the experts and the implemented first three problem solving phases as well as many of the critical thinking skills are addressed by the game. But the open feedback suggests that the game lacks elements to support the learning process of students with different skill levels.

Table 2. Degree of agreement regarding the question of whether the used gamification elements are motivating, using a 5-point Likert scale (1 – strongly disagree, 5 – strongly agree), median, range.

Gamification elements	Degree of agreement (5-point Likert-scale*)

	Median	Range (min-max)
Player avatar	5	4 (1-5)
Quests and subquests	4	3 (2-5)
Interaction with NPCs (non-player characters)	5	2 (3-5)
Use of key items	5	1 (4-5)
Design of the virtual world	5	3 (2-5)
Storytelling	5	2 (3-5)
Visual representation of game relevant elements, concepts and items (i.e., color codes in texts)	5	4 (1-5)
Auditive feedback when gaining items or completing quests or subquests	5	3 (2-5)
Ambient noises / sound effects	4	4 (1-5)
Music	5	4 (1-5)

* 1 – strongly disagree, 5 – strongly agree

Furthermore, the validation provides us with important information on the average playing time, which must be valued much higher for our target group (10th grade students).

Due to the very small sample size (N=6) and the fact that doctoral students are not the target group of the game the expert rating should be seen as a first qualitative pre-study. It has to be mentioned that the potential of the game to foster critical thinking skills has not been measured yet.

The further steps are to improve the first part of MINT-Town, based on the expert rating, and to develop the chemical part of the game, before we can evaluate them with the target group.

References

[1] E. Care, P. Griffin, and M. Wilson, *Assessment and Teaching of 21st Century Skills: Research and Applications*. Springer International Publishing, 2018.

[2] M. Sailer, J. U. Hense, S. K. Mayr, and H. Mandl, "How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction," *Computers in Human Behavior,* vol. 69, pp. 371–380, 2017, doi: 10.1016/j.chb.2016.12.033.

[3] P. Buckley and E. Doyle, "Gamification and student motivation," (in English), *Interactive Learning Environments,* vol. 24, no. 6, p. 14, 2016, doi: 10.1080/10494820.2014.964263.

[4] J. Hamari, J. Koivisto, and H. Sarsa, "Does Gamification Work? - A Literature Review of Empirical Studies on Gamification," in *47th Hawaii International Conference on System Science*, Waikoloa, HI, USA, 06.-09.01.2014 2014: IEEE, doi: 10.1109/HICSS.2014.377.

[5] R. H. Ennis, "Critical Thinking: Reflection and Perspective - Part I," (in English), *Inquiry - Critical Thinking Across the Disciplines,* vol. 26, 1, p. 15, 2011.

[6] R. Scherer, J. Meßinger-Koppelt, and R. Tiemann, "Developing a computer-based assessment of complex problem solving in Chemistry," *International Journal of STEM Education,* vol. 1, no. 2, p. 15, 2014.

[7] R. Tiemann and A. Annaggar, "A framework for the theory-driven design of digital learning environments (FDDLEs) using the example of problem-solving in chemistry education," *Interactive Learning Environments,* pp. 1-14, 2020, doi: 10.1080/10494820.2020.1826981.