Using gamification as an online teaching strategy to develop students' 21st century skills

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Abstract. This paper reports on a study investigating the use of gamification as a teaching strategy in an online setting for developing upper-secondary students' 21st century skills (i.e., collaboration, critical reasoning, communication, solving complex problems, and being able to use and manage digital tools and devices). More specifically, the study aimed to empirically explore pedagogical design perspectives as well as students' and teachers' experiences on what opportunities and challenges they perceive about gamification teaching designs in this context. University students co-created the gamification activities' design and the participating teachers chose virology and immunology (Biology 2 for upper-secondary schools in Sweden) as the topics. The study was conducted during Spring 2020 and in total 26 upper-secondary students, 2 teachers, and 7 engineering students studying in the Master of Science programmes participated. The empirical material is based on observations during the online tests in which the school students tested the university students' design, a survey with the school students, post-interviews with the teachers and the university students, and the university students' written report as a mandatory assignment in their course. The findings illustrate three themes: 1) developing pedagogical design principles for online gamification activities, 2) the school students' experiences, and 3) the participating teachers' experiences. The findings show that designing for gamification teaching in an online setting with a specific purpose in developing students' 21st skills is quite a complex process. The participating teachers, for example, perceive gamification teaching designs as a catalyst for motivating and engaging students' learning to a high extent, but the challenges they experience concern foremost how to design tasks and assess an individual student's knowledge in collaborative assignments. The collaboration between the university and K–12 education concerned combining the different competences in the TPACK-model, and in addition aligning expressed motives and goals towards an applied teaching design. This presented study is an aspiration and a practical example of directing towards development of smart learning ecosystems.

Keywords: gamification, online teaching, 21st century skills, smart learning ecosystems, pedagogical balance,

1 Introduction

The ongoing global digitalisation of society and technological development means there are new demands emerging in terms of what students should learn and how the school should develop students' skills beyond the basic knowledge to prepare them to live as active citizens and work in a constantly changing society. Rapid technological

development impacts society as a whole, specifically education, research, and the labour market [1] [2] [3]. Suggestions arise about the need to take holistic approaches on, for example, developing smart learning ecosystems [4]. This concept can potentially increase regional and urban development [4]. *Smart* in the concept of smart learning ecosystems refers to intending to go beyond the meaning of just intelligent. This concept emphasises using digital technologies and additionally includes the human perspective as intellectual capital [5]. According to Giffinger et al. [6], including this holistic approach and focus embraces smart governance, smart economy, smart environment, smart mobility, smart living, and not the least, smart people. However, this in turn requires a strategy of producing highly skilled people. Thus, a driving factor for economic development in a territory requires a high presence of skilled people with different competences [5]. This will in turn shed light on contemporary learning systems and learning environments (e.g., schools and universities), and how well they adapt to focusing on developing future competences that students need in preparation for living and working in a constantly changing digitised society. Furthermore, raised requirements on what today's students should learn in school concern, for example, general knowledge and skills such as collaboration, critical reasoning, communication, solving complex problems, and being able to use and manage digital tools and devices. These skills are usually referred to as 21st century skills. Organisations (e.g., Partnership for 21st Century Skills, the North Central Regional Education Laboratory, Metri Group, OECD, the National Leadership Council for Liberal Education, and America's Promise) have developed their own frameworks concerning content and processes for teachers and for students' schooling [7].

However, in a digitised society, and therefore to a higher extent than before, an employee must be able to think creatively, collaborate, solve complex problems, and make full use of the opportunities digitalisation offers. However, there is a lack of clarity as to what the concept of 21st century skills really means and what these skills really are, in addition, to what direction a digitised education should be moving towards. Many educational reforms have failed, and according to Dede [7], the same terminology of 21st century skills is used, but apparently means different things. Furthermore, teachers perceive the process of digitising and changing the ways they teach as a real challenge [8]. At the same time, due to the current COVID-19 pandemic occurring during 2020, teachers have been given another challenge to master. Teaching has suddenly turned into what can be described as emergency remote teaching, when teaching in upper-secondary schools and universities suddenly has been moved from the school premises to be conducted completely online in a very short time span [9] [10]. In Sweden, for example, in teacher forums on social media and in conversations with several teachers, many teachers apparently describe the situation as being very difficult to change their ordinary classroom teaching to a digital context within such a short time. Further, they describe this sudden change as both stressful and difficult to cope with. Moreover, in conversations with school students, many of them expressed that the new online teaching (e.g., emergency remote teaching, [9] [10]) is very monotonous. Often there seems to be one-way communication in the form of digital lectures the teachers give in combination with tasks for students to solve on their own at home (i.e., perceived by the students as very boring and lessons have the same structure day by day). Not being

challenged enough or just being bored of course affects the students' knowledge and learning processes. According to this background, questions have been raised about whether it is possible to design online teaching where students are able to practice 21st century skills while simultaneously motivating and engaging them for collaboration and learning, for example, directing towards developing smart learning ecosystems [4] [11].

This paper reports on a design-based research study investigating the development of pedagogical design principals and the use of gamification as a teaching strategy in an online setting for developing upper-secondary students' 21st century skills. More specifically, the study aimed to empirically investigate opportunities and challenges from a design perspective and foremost, to explore university students', school students' and teachers' experiences with gamification teaching designs in an online context.

The research questions addressed are as follows:

1. How can a gamification activity be designed in an online context for the purpose of developing students' 21st century skills? What opportunities and challenges are the participating university students' experiencing concerning a pedagogical design perspective?
2. How do upper-secondary students perceive gamification in an online context and what are their experiences in terms of perceived opportunities as well as challenges?
3. How do teachers perceive gamification as a teaching strategy in an online context and what are their experiences concerning opportunities as well as challenges?
4. What implications are there concerning a collaborative design process between university and K–12 education?

2 Background and literature

2.1 Gamification as an emergent teaching strategy for developing 21st century skills

During recent decades researchers have argued for a need to change traditional teaching approaches, especially in relation to an increasingly digitised society and societal changes rapid technological development causes as well as the increased use of 'new' emergent digital technologies in education [12] [13]. For example, Jahnke [13] stresses the importance of changing learning approaches towards what she calls learning expeditions or learning walk-throughs for students, where the students can make independent decisions and involve self-reflections during their learning processes. Jahnke [13] argues further that this type of teaching, designed towards a learning expedition, is closely related to autonomy and learner centredness and in addition, that the teaching design includes aspects of playfulness and creating new artefacts. In line with Jahnke, Jonassen et al. [14], stresses the importance of technology use for students' learning. Further, they argue that when students are allowed to use technology for complex problem-solving tasks and information-retrieving purposes, it may benefit their learning processes. However, for teaching with technology to be effective, it requires a shift

from traditional instructional practices to a more constructivist approach. For teachers, teaching with technology thus necessitates weaving together three specialised knowledge sets: content knowledge, pedagogy knowledge and technology knowledge (e.g., TPACK [15]). Jonassen et al. [14], stresses further the importance of approaches as student-centred learning for achieving what they term as meaningful learning. Designing teaching as meaningful learning requires a change in teacher behaviour and teacher beliefs. Furthermore, Kim et al. [16], argue that for teachers to increase their levels of technological integration and adoption of new emergent teaching designs, they need proper support.

However, the term *emergent* in relation to using digital technologies is often mentioned as 'new' technologies (e.g., advanced technologies, such as virtual or augmented reality). Using emergent technologies in teaching embraces innovation, creativity and advancements [17]. Further, the concept of emergent technologies includes five attributes: radical novelty, prominent impact, rapid growth, coherence, uncertainty and ambiguity [18].

Considering the term and definition of emergent above, emergent teaching practices, such as gamification or the flipped classroom, are those approaches seen as involving openness and experimentation and include abilities to respond to the ongoing digitalisation of education and the changing circumstances in education [19]. Emergent teaching practices embrace unpredicted benefits and move towards more collaborative ways of working [19]. For example, this could be compared to the research on teaching approaches focusing on developing students' 21st century skills in a digital age and constructing meaningful learning [14], and designing teaching as learning expeditions in schools [13]. Hence, the term and concept of emergent, for both teaching practices and technology use in education, currently is not considered a must-have and is not often used in education practices. However, this is an important perspective and could be seen as a puzzle piece for changing teacher behaviour and teacher beliefs [16] in developing smart learning ecosystems [4].

Moreover, gamification as an emergent teaching approach foremost aims at increasing student motivation and engagement for schoolwork to promote their learning processes and knowledge acquisition. This is specifically intended to improve students' school results. The concept of gamification is used in not only educational settings, but is also various business and industries and the concept is utilised for staff competence development [20]. The teaching strategy consists of an approach to designing school content to be taught as a gaming experience. Hence, it is not about using existing games in teaching, but designing teaching as a playful learning experience for students by recreating a similar strong motivation as games create (cf. learning expeditions). Sailer et al. [21], define gamification as "the process of making activities in a non-game context more game-like by using game design elements." Gamification thus constructs a strong motivation in students for schoolwork, and tries to achieve what Csíkszentmihályi [22] describes as a 'flow experience.' This is a feeling of energised focus, where the students are fully immersed in their involvement, engagement, and enjoyment in the learning process when they are tackling, for example, open-ended problem-solving tasks (cf. learning expeditions). The factor of 'flow' guides every type of well-designed gaming experience, and when students perform school assignments, the given

tasks need to have a complexity level that in turn requires a certain skill level [20]. When designing games, the game developers focus on and attempt to reach the human core driving forces, so a player will achieve strong motivation and engagement to continue playing (e.g., known as levelling-up). Hence, using gamification as a teaching strategy aims at achieving the same strong motivation and engagement for schoolwork in students. This is achieved by taking advantage of these motivational dynamics e.g., using game mechanics and game dynamics when designing teaching activities in class. Designing school content and assignments for students to facilitate their inner 'flow experience' [22] via gamification teaching designs has a direct correlation to improved academic engagement and positive learning outcomes [23]. Dicheva et al. [24], discovered that a combination of using both extrinsic and intrinsic motivational factors (e.g., making use of human driving forces as in game mechanics and game dynamics) could in fact increase student engagement and additionally produce greater student results.

However, these effects in relation to academic performance and what teachers perceive as challenging when designing their teaching in this way are quite scarcely researched [25] [20]. Furthermore, some studies show the concerning challenges of gamification teaching designs, and that traditional eLearning approaches could be more effective in assessing students' knowledge when comparing, for example, gamification and a social networking approach [26]. Moreover, studies also show that teachers continuously struggle in this regard [24]. For example, Mårell-Olsson found in her study [8] that teachers perceive designing gamification activities as a real challenge to find what she terms as a pedagogical balance. The pedagogical balance concerns designing teaching activities in such a way as to create a balance between fun elements in relation to knowledge elements and technology used in the designed gamification activities that in turn will trigger students' knowledge acquisition and learning processes without sacrificing deep learning. Hence, in using gamification as a teaching strategy, the teaching design needs to be carried out in an orderly and systematically manner for it to be a successful injection into education [27]. However, it could be important for today's contemporary education to further explore gamification as a teaching strategy and its effects and to focus additionally on developing students' 21st century skills during their schooling for being part of a so-called smart learning ecosystem [4]. Therefore, this presented study aimed to take a holistic approach on this issue and investigate if, and in that case how, using university students as co-creators [8] for developing gamification activities in K–12 education could be an example of adapting different learning systems (e.g., school and university). This approach focuses on developing competences that both school students and university students need in the future to be able to live and work in a constantly changing digitised society. In addition, the approach presented in this study attempts to meet and investigate teachers' perceived difficulties in designing gamification activities in schools for developing students' 21st century skills via a collaborative design processes with university students.

3 Study context and participants

This study was conducted during Spring 2020 in a time where all upper-secondary schools in Sweden were put in a lockdown situation to prevent the spread of COVID-19 infection. Applying a purposeful sampling [28], an upper-secondary school was selected for the study based on the precondition of providing one-to-one computing initiatives for their students. The two female teachers who agreed to participate had several years of experience in teaching with technology in one-to-one initiatives. In addition, one class of 26 school students participated (mostly aged 18). The school students were in grade 11 in an upper-secondary school within the K–12 education in Sweden. In total, 16 boys and 9 girls participated.

Both participating teachers were upper-secondary school teachers within the STEM-area (i.e., science, technology, engineering and mathematics) and they worked at the same school. One teacher taught chemistry, and the other teacher taught biology. For this specific study, the teachers jointly decided the topic for the gamification activity. They chose virology and immunology, which was a theme in one of the courses in Biology 2 for upper-secondary schools in Sweden. The teachers chose this specific topic because they thought it was suitable for the gamification activity and because they were supposed to teach this topic during the spring term. Further, they justified this topic was suitable for the gamification activity due to the current pandemic situation and how it was affecting students by forcing them to study from home. Hence, since mid-March 2020, the participating school students had only access to online education from home due to the pandemic. This type of online teaching during Spring 2020 is a type of emergency remote teaching situation [29], which is used in a situation when teaching is stopped abruptly and temporarily moved to be conducted fully online.

Further, research shows that effective online teaching and learning, compared to emergency remote teaching, result from careful instructional design and planning, and using a systematic model for design and development [30]. In Sweden, teachers overall have quite limited experiences with online teaching. In addition, teachers in both compulsory and upper-secondary schools in Sweden overall lack knowledge of and experience with using gamification as a teaching strategy. Furthermore, teachers also seem to lack knowledge and experience in how to plan and design teaching and learning for using emergent digital technologies in emergent teaching practices [8], including gamification teaching designs in online teaching settings for developing students' 21st century skills. Because of this, this study collaborated with university students enrolled in the Master of Science programmes to act as co-creators [8] in order to use their creativity, technological competence and design skills to design a gamification activity for an online teaching setting. Collaborating with university students as co-creators for gamification teaching designs in K–12 education has been tested in earlier studies with very good results [8]. In this study, 7 students studying Engineering physics and Industrial engineering and management participated and undertook a mandatory course within their programmes on Work integrated learning for engineers, 7.5 hp during Spring 2020. In addition, the university students had experience with emergency remote teaching since all universities in Sweden were forced in a lockdown situation in mid-March and only online teaching for universities was allowed. The teachers selected the

university students to be participants in the project. The responsible researcher was not involved in their course or in the engineering programmes.

4 Methodology and Methods

This study took a qualitative approach to investigate and expand the understanding of what opportunities and challenges exist when designing an online gamification activity in developing students' 21st century skills. A special focus was on the opportunities and challenges the participants perceived concerning a pedagogical design perspective, school students' experiences after the tests and teachers' experiences in this context. This study was inspired by and includes aspects of design-based research methods, which is a suitable method for conducting both research and design of technology-enhanced learning environments [31].

4.1 Procedure

As mentioned above, the university students were undertaking a 7.5 hp mandatory course on project management (e.g., learning how to conduct a project and work as a project team). The researcher gave them the assignment to act as co-creators [8] in designing an online gamification activity for upper-secondary students with a specific focus on developing school students' 21st century skills. The researcher was not involved in the university students' course or in the engineering programme. In addition, the university students were supervised by an engineering teacher in their course who gave them feedback on the progress of their assignment. Their teacher also focused on giving them support on their developed design processes, and on how well they worked as a project team. Furthermore, the university students' course included several mandatory theoretical lectures on project teamwork and design processes in general. Hence, the university students participated in this study as an assignment in their course to give them an opportunity to practice their theoretical knowledge and skills on conducting a project and working as a project team. However, the university students' course did not include topics such as gamification or game-based learning, and neither did the theoretical lectures.

Besides the fact that the university students' task and focus were on designing and conducting a project, the students had to read literature about design processes and hand in mandatory associated assignments. For example, they submitted a requirement specification in the beginning of the term for narrowing the scope of the project and received feedback on the assignment from their course supervisor. This helped in making their project, as a course assignment, more feasible for their learning.

Hence, the university students' role in this project was to act as co-creators and their task was to plan, design and conduct an online gamification teaching activity for the participating upper-secondary students on the theme of virology and immunology. The researcher responsible for the research project supported the university students along the way in planning and designing the activity. The researcher was also supporting the

university students with organising the tests with the school students and through discussing, for example, what digital technology to use for the designed activity (see figure 1). In addition, the participating schoolteachers supported the university students as experts on the content for the gamification activity (i.e., virology and immunology).

In the first design phase, the university students were introduced to the Octalysis framework (figure 2) to support their understanding and use of game mechanics and game dynamics in the design process. This facilitated the university students' design process and supported their creativity by addressing the core drives from the Octalysis framework in their gamification activity. This helped to foster the school students' inner drive to motivate and engage them to perform their very best when solving the different problems and challenges during the test. In addition, the university students were also tasked to take in consideration the 21st century skills and to combine them with the game mechanics and game dynamics in the design.

Hence, in iterative processes, several discussions were held in phase 1 (see figure 1) about the university students' chosen tasks within the gamification activity (e.g., their constructed design) in relation to the topic the teachers chose. This phase went back and forth several times consisting of design and re-designing processes before a final design was created that the school students would test (i.e., phase 2). Further, the third phase consisted of participants' evaluation of the activity, as where the school students answered surveys and the university students and teachers participated in post-interviews.

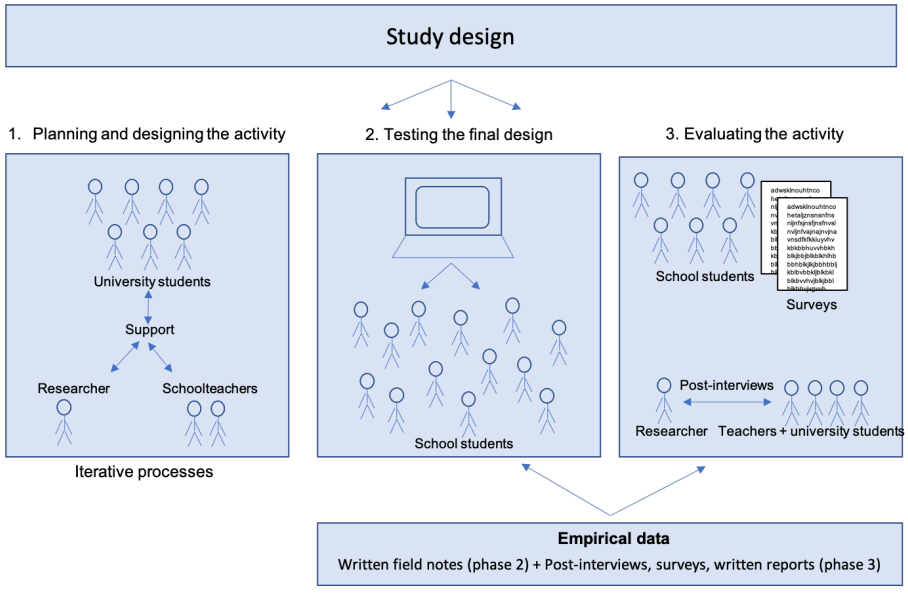

Fig. 1. Study design.

The empirical material was collected through observations with written notes during the tests with the school students (phase 2), post-interviews with both university students and the participating teachers and post-surveys with the school students (see figure 1, phase 3). Further, the university students' written group report was also included in the empirical material. This report was a mandatory assignment for the course they took during Spring 2020. All participants agreed on a research ethics statement based on beneficence, non-malfeasance, informed consent and confidentiality/anonymity [32].

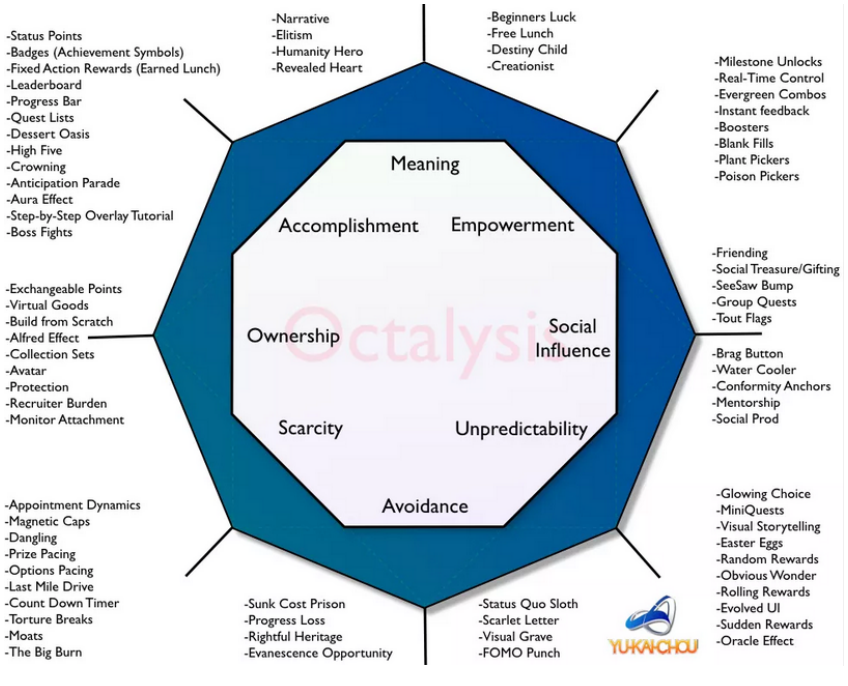

Fig. 2. The Octalysis framework [33] introduced to the university students.

Furthermore, during the tests with the school students (phase 2), the researcher took written observation notes concerning, for example, reactions expressed and communications between the school students and the university students and the participating teachers. For example, the researcher observed the university students' pedagogical activity design (e.g., from the start of the activity to the end), how well the school students understood the instructions, solved the challenges/problems and collaborated with each other. Further, the observations also focused on whether and how the school students needed further instructions if something was unclear and if the university students had to change their instructions to the school students between the two tests (e.g., pedagogical instruction and design) and in that case, why. After each test, an online gathering with the participating school students was held on Zoom, where they orally expressed their feelings and their initial views on the opportunities and challenges they perceived while testing the university students' gamification design.

In addition, post-interviews were held with both the participating teachers and the university students. The semi-structured interviews with the teachers focused on their views and experiences on opportunities and challenges they perceived concerning how gamification teaching designs might affect students' knowledge and learning processes in an online context. For example, one open question was, "What pedagogical opportunities and challenges are there concerning gamification teaching designs in relation to students' knowledge acquisition and learning processes and in addition, how can you assess their individual skills?" The post-interviews with the university students were foremost focused on their experiences concerning the pedagogical design processes, opportunities as well as challenges they perceived during their design process (i.e., from first idea to the actual gamification activity tested), and their view on the tests' outcomes. Lastly, a post-survey with the school students was conducted to gather more information on their individual views on the opportunities and challenges they perceived while testing the gamification activity. The post-surveys with the school students consisted of open questions addressing topics such as how they perceived the activity from their point of view; for example, if they perceived the tasks as fun, motivating and how it was to perform the tasks online. In addition, questions included topics such as how the groups worked together and if they collaborated well in the group. Further, questions were also asked about how the school students were perceiving each group members' contribution in the discussions concerning, for example, if they perceived their group members listened to their suggestions on how to solve a presented problem.

5 Theoretical framework

The theoretical framework for this study is based on Leontiev's framework of activity theory [34], where the key concepts are *motives*, *goals*, *actions* and *operationalisation*. Activity theory allows an exploration of the intention of a planned activity in a context in relation to material, social relations and tools used. The focus in an activity system, for example as in this study, is on not only the participating individual's actions, but also group actions in relation to the activity system. Hence, the interplay between the aspects of the key concepts (i.e., motives, goals, actions and operationalisation) and participants' actions within the activity system may be investigated. Nardi [35] explains that it is also important to study the role of the artefacts or tools used in the activity systems and how they affect actions within the system. For this present study, the design and tests of the gamification activity were an activity system, where digital tools were used for facilitating both the communications and the interplay between the participants. The key concepts (i.e., motives, goals, actions and operations) could be transferred into the context of teaching as an activity system. For example, teachers carry out operations in the classroom (the context of online teaching for this study). Further, the operations in the activity theory could be different routines, procedures or practical examples of a topic conducted in a classroom with students, this is in relation to preconditions within a school organisation. These *operations* in the classroom are, in turn,

constructed of combined *actions* and these actions are related to the *goal* and the intentions of the teaching activity (i.e., *motive*) the teachers are trying to pursue (see figure 3).

For this study, the chosen framework of activity theory frames the study on different levels. For example, the *motive* for this study is an intention to investigate whether and how gamification teaching designs in online teaching develops students' 21st century skills. The goal is to investigate and understand the opportunities and challenges participants are perceiving. The *actions* taken are designing and examining the gamification activity to reach the motive and goal. The operations within this specific activity system are the designed teaching activity conducted online (i.e., the tests with the school students).

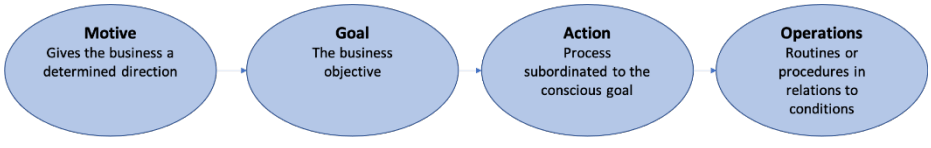

Fig. 3. The key concepts within Leontiev's activity system [34].

5.1 The analysis processes

To identify emerging patterns and themes as well as constructing an understanding and meaning of the collected empirical material, this study used thematic analysis [36]. This analysis process assists a researcher who is searching for insight and is a process for encoding qualitative information. The encoding phase includes multiple readings of the material as an iterative process. In this process, two perspectives of 'seeing' and 'seeing as' [37] are included, whereas the 'seeing as' identifies emerging themes in the empirical material to search for the significance of repetitive patterns [38]. For example, emerging themes could be a definition of utterances all participants in a study made or a single statement that had a great emotional or actual meaning (i.e., significance) [36]. For this study, the constructing meaning phase (i.e., seeing as) was conducted by searching for themes on a more abstract level. This was performed by combining observed behaviour and communication between participants during the teaching design test and to what they explicitly or implicitly said in the interviews. In addition, the school students' responses to the survey and the university students' written report were analysed concerning perceived opportunities and challenges (e.g., data triangulation).

More specific, to analyse the collected empirical material, Nvivo (i.e., a computer software for coding qualitative data) was used for categorizing and coding the data. This was done by searching for signs and patterns in the interviews, surveys and written observations notes regarding participants' utterances concerning what they explicitly or implicitly said, such as utterances concerning opportunities or challenges teachers and university students perceived when designing gamification activities. In addition, other dialogue might have been centred on the school students' reflections on the tested online gamification activity compared to, for example, their ordinary teaching con-

ducted in the classroom before the pandemic. Furthermore, the university students' descriptions on the developed design principles and what they wanted to achieve with the different tasks were coded as actions and operations. The school students' utterances were coded and compared to 21st century skills. These utterances concerned their view on opportunities and challenges they perceived from the online gamification activity in terms of how to use, for example, the technologies used in the test, collaboration among group members in different tasks and if they were able to discuss and reason critically during the 'game'. Further, how the teachers' described what gamification activities overall might offer concerning both opportunities and challenges and what they wanted to achieve with their own teaching (e.g., motives and goals). For example, their utterances regarding student knowledge acquisition, were coded as their expressed motives and goals in teaching. Moreover, categories indicating similar types of expressed motives, goals, actions and operationalisation were then clustered in iterative processes. The final step consisted of analysing where the clustered categories were and then forming into the emerging themes. Hence, the presented emerging themes in the next section of the findings were formed and derived from multiple iterative analysis processes.

6 Findings

The findings are presented in three themes concerning developing pedagogical design principles for online gamification activities, school students' experiences, and the participating teachers' experiences of the designed gamification activity. The three themes are specifically focused on opportunities and challenges the participants were experiencing in this context. The quotations presented in this section should not be regarded as merely evidence, but more as illustrations of the themes that emerged during the analysis process.

6.1 Developing pedagogical design principles for online gamification activities

Developing steps in the design process. The university students' design process consisted of several steps, such as:

1) *Preparing the requirements specification of the assignment*. This specification was a mandatory assignment in their course and had to include areas they were not focusing on for this specific project. The students also received feedback on this task from both their teacher and the researcher. They had to re-write the specification after comments from both the teacher and the researcher to make the plan clearer and more feasible.
2) *Theoretical studies on key concepts of gamification and the meaning of the concepts of 21st century skills and online education*. To gain more knowledge on these concepts, the university students started with theoretical studies defining what these concepts included, what these concepts could be used for and for what purposes by searching for research articles and studying the introduced Octalysis framework

(e.g., elements to consider when designing gamification activities). In addition, they searched for practical examples of gamification activities for educational purposes.

3) *Interviews with the participating schoolteachers* as experts on the chosen content and how to adapt the content to the school students' age and knowledge levels. The schoolteachers also provided feedback during the design process regarding the planned activity for identifying the right level of knowledge according to the school students' age and the chosen topic—especially regarding the specific design problems/challenges for the school students to solve in the designed gamification activity in terms of difficulties, etc.
4) *Idea generation and concept construction phase*. After collecting data on the concepts of gamification and 21st century skills, and after interviewing the teachers on the content, the university students started the idea-generating phase. They started this phase by brainstorming and categorising suitable online digital technologies and pedagogical activities in relation to content, gamification and 21st century skills. For example, they searched for what types of online platforms they could use for constructing their designed gamification activity. After the idea-generating phase, they made decisions on what platform and pedagogical methods to use, and after that, they began creating their own developed gamification framework by constructing logic designing sub-activities and a final challenge.
5) *Testing the developed design with the school students*. At the end of the spring term, the university students were able to test their design with the participating school students. The school students were divided into two groups and hence, two tests were conducted. After each test, the university students' designs were first evaluated orally by gathering the two groups after each test was finished. Later, a post-survey was sent out to the school students to obtain individualised answers about the opportunities and challenges they experienced.

The designed gamification activity. The university students designed a gamification activity that was similar to what is known as a treasure hunt. The main activity was divided into smaller sub-activities that ended up with a final challenge the school students had to solve (see figure 4). The school students worked in groups and collected points and specific clues in the sub-activities that they later could use in the final challenge. When all the challenges/problems were solved (i.e., sub-activities and the final challenge) a winning team was selected.

Moreover, collecting points and clues in the sub-activities were two strong driving forces aimed to increase school students' inner drive and motivation to continue an activity (e.g., *development and accomplishment* and *scarcity and impatience*, [33]. According to the university students, these two concepts were the foundation of their designed gamification activity. In relation to developing students' 21st century skills, the university students decided that the school students would work in groups to foster their collaboration and problem-solving skills, which in turn is related to the Octalysis framework as *Social influence* and *Relatedness* [33].

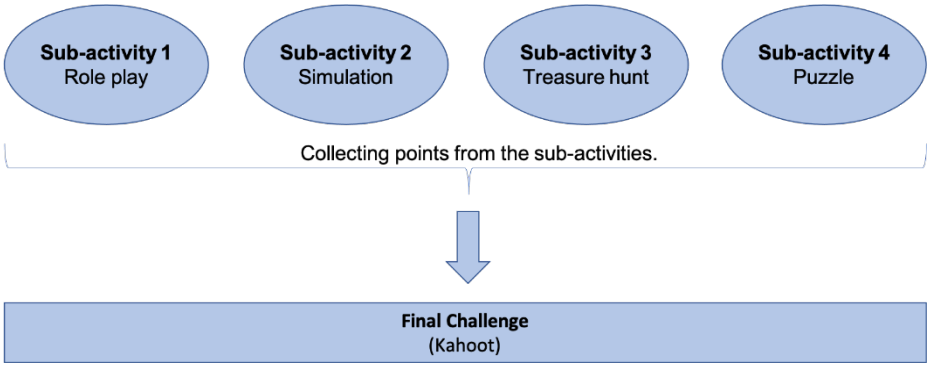

Fig. 4. The university students' gamification design.

The role-play. The gamification activity was divided into 4 sub-activities that ended in a final challenge (see figure 4 above). The first activity was designed as a role-play where the school students were supposed to imagine they were a team of doctors discussing solutions for 5 questions/problems about a virus and the immune system. The school students handed in their solution after finishing the first activity. The university students evaluated their solutions and gave them different points according to how correct the groups' answers were. The role-play was designed to relate to the core drives of Epic meaning and calling, and of Ownership and possession in the Octalysis framework.

Simulation. Further, the next activity (i.e., sub-activity 2) consisted of an interactive simulation about how viruses are spread in a population, in addition to a quiz to solve about the simulation. The school students' task was to run the simulation several times and change the amount of the vaccine to see how it affected a population. The quiz to solve in this activity consisted of questions concerning how vaccination affects the virus's spread in the population. The quiz was used to ensure that the students had experimented accordingly to the instructions, and understood the simulation tool and the positive impact vaccination might have in a population for decreasing a societal spread of an infection. According to the university students, this activity was designed to reach the core drives of Empowerment of Creativity, Feedback, Unpredictability, and Curiosity in the Octalysis framework.

Treasure hunt. The third sub-activity was designed as a treasure hunt where the school students were supposed to find the correct words for descriptions given within the topic of viruses and the immune system. The school students were encouraged to search for the right answers using multiple resources, such as their textbooks and do research on the Internet. This activity was designed in relation to the core drive Development and Accomplishment.

Puzzle. In the fourth sub-activity, the school students had to connect different virus names with their corresponding structures. This activity involved solving a puzzle to foster their creativity. According to the university students, this activity was designed in relation to the core drive of Empowerment of Creativity and Feedback.

The final challenge. The final activity consisted of a quiz in Kahoot (a game-based platform for creating self-learning games as user-generated multiple-choice quizzes), whose questions were mostly based on the 4 sub-activities. The school students were thus rewarded for having been active and attentive in the previous sub-activities. This activity was designed in relation to the core drives of Epic meaning and Calling. Research has shown that using Kahoot in teaching positively affects learning performance and classroom dynamics [39].

Digital tools for conducting the gamification activity. To carry out this designed online gamification activity framework, the university students searched for a number of various online tools that were needed to test the school students. For example, they chose two different tools to function as being in the centre of the activity. The chose Zoom, an online video communication system, to communicate between all participants, and they chose a website that the university students created themselves, where the 5 activities' instructions were presented (see figure 5). Zoom was used as a gathering place where all participants were communicating. The built-in breakout-rooms in Zoom were used for the school student groups (e.g., competing teams) so they could have separate rooms for their groups to share their computer screens and discuss with each other undisturbed.

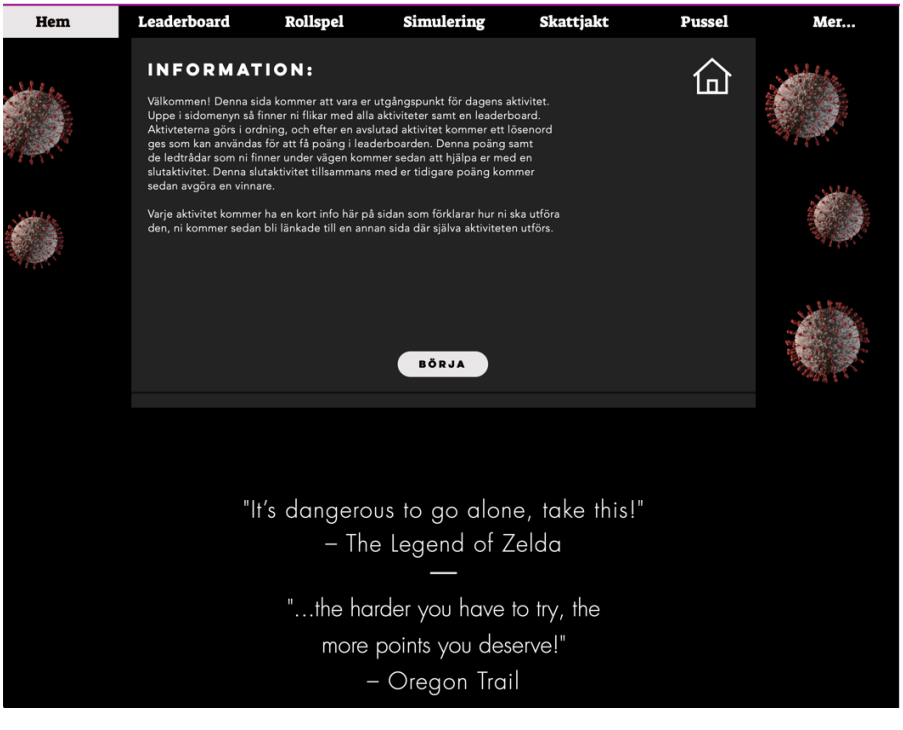

Fig. 5. The website where the instructions of the activities were presented (text in Swedish).

The website was used as a base for the whole activity where the school students could find information about all the activities and instructions on how to carry them out

(see figure 5). The website was also used for collecting the competing teams' points after finishing each sub-activity in the form of a leaderboard. The school students registered their points themselves on the website with a password they received after a completed activity. In sub-activity 1 (the role-play), Google Docs was used as the school student groups' word-processing document where they could discuss solutions using Zoom and write simultaneously in Google Docs. In the sub-activities 2–4, a tool called Quizmaker (an external quiz-making website) was used for creating the quizzes. The university students prepared in advanced the website so the teachers could add or remove both teams and points as needed, if the participating teachers wanted to use the designed activity with another class of school students in the future.

The outcomes of the tested gamification activity. According to the university students in the interviews, they were very pleased with the outcomes of their design from the two tests, even if some problems occurred. The university students were especially pleased that their design worked so well despite using multiple gamification elements in the same activity, giving an example on how to design a gamification activity that could be applied in K–12 education. The schoolteachers were also pleased with the outcomes of the activity and they asked the university students to write an instruction on how they could use this activity on their own in the future. For example, one of the university students expressed:

> *"I would say that we achieved the purpose of this project. The school students had to collaborate online and be creative to come up with solutions to the problems, which is one of the cornerstones of 21st century skills. Afterwards, the teachers in fact asked us if they could get instructions on how they can use our website and our activities in the future. That was really fun."*

However, according to the observation notes, some problems occurred during the tests. At some point during the 'game' the school students needed help and support from the university students to be able to continue their activity. For example, in the first test, some school student groups did not understand the instruction on how to use the passwords they received when finishing a sub-activity. In the beginning of the second test with the next groups of school students, the university students changed their instructions on how to use the passwords. This part worked better during test 2. Furthermore, other problems that occurred during the two tests concerned the website's design. For example, the final activity (Kahoot) was only visible if the school students had their website in full screen mode. This problem initially was discovered in the first test when several groups could not find the final challenge and asked for help and support. The second problem that arose was that one of the school student groups realised they could use the same passwords more than once and, in this case, got several extra points they had not earned by solving the challenges. The university students corrected this before selecting a winning team.

The university students' design process. According to the students, they struggled somewhat during their design process on how to understand and handle the different

expectations they had within the project. This concerned, for example, requirements for fulfilling criteria for their course, and how to combine this with the requirements the researcher had for the research project. As one of the students expressed during the interview:

> *"This was something we had to consider even to the final end. What are we expected to present at our course? What is the product we are supposed to present for our course for fulfilling an engineering product according to the course criteria? We had a fairly good idea of the researcher's expectations of the research project, but it was a bit tricky to understand how to combine it with the course criteria sometimes. Luckily, we had good support from our teacher in the course. The assignments we had to hand in during the term also helped a bit for knowing what they [the teachers in the course] expected us to do."*

Furthermore, concerning the students' own design processes, they stated during the interview that the biggest challenge to overcome was in fact during the beginning of the project. The challenge they perceived regarded figuring out where to start and understanding what they were actually required to do. One of the students said: "It was hard in the beginning to understand how we could combine all the aspects from gamification [i.e., game design elements] to a designed activity for the school students. How can we go from theory to practice? How can we design an activity that is not merely perceived as fun or a just game? This was in fact the hardest part in the project to grab." According to the students, they were searching for many different ideas and using brainstorming as a technique for collecting ideas before deciding what tasks to use. However, apparently this was not an easy process. One of the students explained: "When time was almost running out, we just had to decide what tasks to use. The help from the schoolteachers was also really fantastic in this process. It felt so good being able to ask them and get feedback on our design before a final decision was taken."

It possibly was not an easy design process for the university students in terms of combing all the aspects of the criteria given in the project. This included, for example, constructing a design with stated motives and goals for the project, even if they were clarified to a high extent, into an actual design where actions and operations in the activity were in line with expressed motives and goals. Doing this required a process of acquiring an understanding for expressed motives and goals for the research project and of the criteria for the gamification designs. In addition, they had to take into consideration what 21st century skills actually are and how to involve them in the design. Furthermore, the process for the university students also required transforming their theoretical understanding to an applied design (e.g., actions and operations). In this case, collaborating with the schoolteachers for feedback and discussions about the design that were held in iterative processes supported the university students in their design process to a high extent.

6.2 The school students' experiences

However, did the university students develop a design that the school students perceived as not merely fun or like playing a game? When the participating school students were asked in the survey about their own experiences on the gamification design, there was no doubt that they overall really liked the gamification activity. This was confirmed both in the oral gathering with the two groups and in the post-survey. In the survey, 24 of the school students (approximately 90 %) answered that they were positive towards teaching that were organised as an online gamification activity, and 21 school students (approximately 80%) answered that they were active during the whole activity. On questions concerning collaboration, 26 answered that the collaboration in their group worked well and 19 (approximately 70%) thought that all group members in their group contributed to solving the presented challenges/problems and the group's result. Most of the school students, approximately 90%, answered that everyone in their group had a chance to speak and suggest solutions, and that they felt the other group members listened to them. For example, as one school student expressed it: "I like to compete and therefore it was motivating. It was fun to work in a group, also good for my learning because I can learn from the others." Another school student answered: "It was fun to work in a new way so that it doesn't become the same old as usual. Since it was a competition, it made me more motivated since I want to win. It was also fun that it was designed a bit like a game with various challenges and clues." A third student explained it as: "The task was motivating and engaging, as always with competitions. It was extra motivating to see the result after each activity, then you knew if you needed to perform better to get in the lead."

The school students expressed different challenges they encountered during the activity, such as not knowing to how to navigate the platforms used in the activities (i.e., Zoom and the website). One student described it as: "It was stressful and the technologies we had to use were a bit odd." However, even if most of the students thought that the gamification activity was fun and motivating, and to some extent fostered their learning, two of the school students (approximately 10%) answered that they did not like this particular activity and preferred ordinary teaching in the classroom. They also stated that this type of teaching did not foster their learning processes. One of these school students described it as follows: "I learn better when teachers have ordinary lectures about something and when we have regular work in class. However, it is a new way to teach and I can believe it is probably something that can engages others."

School students' experiences of online gamification teaching worked quite well for most of them and possibly motivated and engaged their knowledge and learning to a high extent. This is could be especially true when a gamification activity is designed with a specific focus, such as fostering collaboration and knowledge discussions among students. One of the school students confirmed this: "We really got a chance to test our knowledge and it was obvious what we needed to practice more on it." Thus, the design of the gamification activity gave the school students an opportunity to informally test their knowledge on the content, and apply and use their collected knowledge to find and present the best solutions on the problems they had to solve in the activities (cf.

Vygotsky's zone of proximal development). The design and the implementation of this specific gamification activity to some extent fostered knowledge creation and made learning processes visible for them. In addition, the activities' design offered the school students an opportunity to use each other's different skills to solve the problems/challenges in a way they would not have been able to do individually.

However, in terms of the online gamification activity designed and implemented as in this study, some students might not perceive it as more motivating and engaging. Some students who did not feel as motivated as their classmates could be more used to ordinary classroom teaching and thus those traditional learning strategies work better for them in a classroom setting. In addition, they might have developed learning strategies focused on how to show their skills better in the classroom. On the other hand, almost 90% of the participating students in this study stated they were more motivated to solve the problems and challenges and to collaborate with their classmates than they were with ordinary teaching methods. However, even if most of the school students expressed both in the gatherings after the tests and in the survey that they had quite a strong motivation and engagement for the implemented gamification teaching design, it is imperative to keep in mind that this was the first time these students were presented with a gamification teaching activity during their school time. Hence, it is not possible to disregard that an initial impression and a completely different teaching design compared to ordinary teaching could also affect their positive feelings, perceptions of motivation and their activeness during the tests compared to, for example, the teaching during the lockdown in Spring 2020 (e.g., emergency remote teaching).

6.3 The participating teachers' experiences

In the interviews with the teachers, it was clear they saw several opportunities with the online gamification teaching design concerning, for example, fostering collaboration and problem-solving skills and using online resources. One of the teachers described questions concerning school students' collaboration and being active during the activity as:

> *"They have been very active in the break-out rooms, and it has been very fun to listen to their discussions. All groups have been active doing the tasks trying to solve the problems the best they can. I was a bit surprised in fact, that they were so active. I think they had immunology a while ago, and this activity actually strengthened their knowledge."*

The other teacher explained: "The great profit as a teacher was being able to go in and out so easily to the different rooms and listen to the groups' discussions. It was very fun." For the question regarding the teachers' opinions about the different activities during the 'game' and how well they were motivating and engaging the school students, they described the role-play (i.e., the first sub-activity) as the less engaging activity compared to the others. One of the teachers said: "The first activity was the less engaging activity, I think. The task was quite like what they are used to doing in school." The

other teacher described how she liked the simulation activity the best. “The simulation exercise was the best. Some students were very fast. That exercise was simply good and useful for understanding how viruses are spread.” Both teachers perceived that the school students very much liked Kahoot as the final challenge. One of the teachers explained it as: “Many of the students shouted out with joy when they came to Kahoot. They like Kahoot a lot.” The other teacher confirmed this statement by saying: “Yes, it worked really well.”

For questions regarding how they, as teachers, can assess students’ knowledge in gamification teaching designed as it was in this study, they both stated it is quite hard to assess the students individually when they were collaborating. When they were reflecting on using Zoom as an online tool for fostering communication and collaboration on specifically developing students’ problem-solving skills, one of the teachers explained: “It’s hard to make equal groups in terms of their levels of knowledge and skills. For those groups that have some of the really good students, it is easier for them to get good results.” The other teacher answered:

> *“But, if you, as a teacher, have larger assignments in seminar form, this tool would use these rooms so that you can walk in and out between groups, and then the assessment could probably work quite well. In this situation, I don’t know. It was getting a little bit too messy for me considering that sometimes it was too stressful for the students regarding the fact that they had far too little time to finish an activity.”*

In summary, both participating teachers perceived and described gamification teaching designs as a motivating and engaging pedagogical strategy that could foster students’ motivation and engagement to a high extent as well as develop their problem-solving skills and those concerning collaboration. The teachers especially perceived this type of gamification design as an opportunity to repeat knowledge and an opportunity for the students to apply their existing theoretical knowledge on problem-solving tasks. However, they saw multiple challenges regarding how to design an activity for being able to assess the students’ knowledge individually and their ability to collaborate, reason critically, communicate, solve complex problems, and use and manage digital tools and devices (i.e., 21st century skills). One of the teachers stated: “The gamification activity could be really useful as a repetition of knowledge, but maybe not as an examination only. Not as a pure examination for grading, I have a hard time seeing that.” The other teacher also described the difficulty of designing tasks for assessing students’ knowledge and abilities individually in school activities when students are working together in groups and are collaborating:

> *“It all depends on the grade level of the assignments. That is, if having an examination that is only passed or not passed, then it makes it a little less demanding. Then there will be more of right or wrong answers, but, if you want to assess ‘A’ qualities, it is very difficult to do that in a context like this. It requires much more analysis and it is hard to be able to draw conclusions about their actual knowledge and such things.”*

The teachers expressed this design process as a complex one to handle. This concerned, for example, in terms of how to design actions and operations in line for achieving stated motives and goals. In addition, it required the teachers to not only design tasks for their students to solve in groups for addressing the 21st century skills, but also take into consideration how they can assess each student's knowledge and abilities without forgoing the opportunity for students to collaborate in the learning process. This could be compared to what one of the school students expressed above, that they had a chance to test their knowledge and that it showed what they needed to practice on more. Further, the complexity to align actions and operations, as the teachers expressed, could be facilitated by the collaboration and in discussions during the design process with the university students, as it was in this study. Hence, as described above, the learning process for the schoolteachers in this collaboration also consisted of a transformation of the theoretical understanding towards an applied design where the concepts of motives, goals, action and operations were aligned during the design process.

7 Discussions and Conclusions

Using gamification teaching designs as a strategy in the online context to develop students' 21st century skills is thus quite a complex process. The gamification activity presented in this study, as constructed in co-creation [8] with the participating university students, was designed with a motive and goal in focusing on developing students' knowledge acquisition and learning processes for developing 21st century skills. The university students were offered the Ocatlysis framework [33] as a starting point for designing the activity to reach the participating school students' inner drive to be motivated and engaged in solving the presented challenges/problems. This study's emerging results contribute to a pedagogical perspective on teaching strategies for developing smart learning ecosystems [4]. Giovannella [4] argues that smart ecosystems are strongly related to highly skilled inhabitants and to the possibilities to produce highly skilled people. This is related to the global arguments raised about needing to change teaching and learning approaches [12] [13] [14] in developing students' skills beyond the basic knowledge for preparing them to live as active citizens and for being able to work in a constantly changing society. For example, this involves the impact that rapid digital technological development has on society as a whole and especially the labour market [1] [2] [3]. *Smart* in this case, is related to a research design fostering a teaching strategy by designing an activity system [34] in a technology-enhanced learning environment where the university students' technology and design skills are used for supporting the school students' state of flow [22] and their learning processes in terms of developing their 21st century skills. In addition, the collaboration between the university students and the schoolteachers during the design process facilitated their respective transformation processes of aligning motives and goals towards applied actions and operations.

Furthermore, even if the participating teachers in this study perceived gamification teaching designs as a catalyst for motivating and engaging students in learning, teachers' overall preparedness for this teaching strategy seems to be quite low [8]. This lack of preparedness could be defined as teachers lacking knowledge of design processes, e.g., from the first idea to the actual operation in the classroom, when they consider designing teaching as a new practice (i.e., gamification). Along with this, they must combine the knowledge areas in the TPACK model (i.e., technological knowledge, pedagogical knowledge and content knowledge) in technology-rich learning environments [15]. Mårell-Olsson [8] terms this challenge as finding the pedagogical balance. This primarily concerns the challenge of designing teaching with a balance between content to be taught versus having knowledge about what pedagogical methods work best in relation to what digital tools to use. Koehler et al. [15], argue that it is necessary for a teacher to have content knowledge, pedagogical knowledge and technological knowledge (i.e., TPACK) when designing teaching in a digitised learning environment. Hence, in a rapidly changing digitised society, teachers must have this knowledge and be able to combine these competences when designing teaching (i.e., finding the pedagogical balance). Further, this design-based research study is an activity system that intended to explore a learning ecosystem where collaboration with university students could be seen as having access to their creativity and technological competence (e.g., technological knowledge). In addition, this fosters a learning ecosystem in which the collaboration by using the university students as co-creators [8] who designed the gamification activity (e.g., pedagogical knowledge) for K–12 education. Furthermore, this also concerns a collaboration with the participating teachers as experts on the content (e.g., content knowledge). The collaboration between the university students and K-12 education in combining the different competences during the design process, is an aspiration for developing smart learning ecosystems [4]. This study is also an aspiration to connect our future engineers and their teachers responsible for the engineering programmes and K–12 education in the local area by offering an opportunity for the students to apply their theoretical knowledge into practice.

Moreover, the EdTech business is one of the fastest growing industries in the world and the education system is just at the beginning of its digitalisation journey. Hence, many of our future engineers probably will work in companies and industries developing digital resources for schools and K–12 education in the coming future. Therefore, it is important to put in the effort to increase what Giovannella [4] designates as the "here I feel at home effect" and foster a sense of belonging for university students in this area (p.19). Moreover, future engineers also need to experience how developing resources within the K–12 area could be seen as attractive. Hence, increasing collaboration between universities and the surrounding society, for example with K–12 education as in this presented study, might offer an opportunity for university students to practice their theoretical knowledge in a realistic environment (e.g., aligning motives and goals towards applied actions and operationalisation). In addition, this type of collaboration could also increase the school students' sense of what Jonassens et al. [14], denominate as meaningful learning. Jonassen et al. [14], argue that teaching designs must shift from traditional instructional practices to a more constructivist approach for

students to achieve meaningful learning. This could be related to what Jahnke [13] defines as a necessity to design teaching as 'learning expeditions' in schools. Furthermore, constructing and investigating a smart learning ecosystem as in this study supports the university students' opportunities to transform theoretical knowledge to an applied design and test the outcomes in a realistic environment. It is also about expanding and supporting the schoolteachers' knowledge and learning process in aligning, for example, their expressed motives and goals (i.e., what they want to achieve in their teaching), with actions and operations in the teaching design in terms of using gamification as a teaching strategy for developing school students' 21st century skills.

In addition, this type of collaboration between university students and K-12 education develops new teaching practices that are an example of fostering school students in increasing their propensity to apply for studies in higher education. In sum, using gamification as a teaching strategy for developing school students' 21st century skills is an attempt to direct towards constructing smart learning ecosystems, [4] but this requires organisational changes in the future for both universities and K–12 education. However, this study has shed light on contemporary learning systems and learning environments (e.g., schools and universities), and how a collaboration between these two learning systems can be conducted for focusing on developing competences that both school students and university students need in the future. In addition, this study further sheds light, or at least raise questions, on how K–12 education and universities might prepare their students at both levels to live and work in a constantly changing digitised society.

8 Limitations and recommendations for future research

This design-based research study is a relatively small study, and a methodological concern is the participant selection. If this study had included more participants, cases and interviews, the study would have obtained more extensive data and richer nuances. However, time limitations made further data collection impossible concerning, for example, the university students having other mandatory courses they had to attend during the term. Another methodological concern is the chosen theoretical framework [34] and applied thematic analysis approach [36]. If a more theory-driven approach had been used, the study could have obtained different results. However, the chosen designed-based research method, in combination with the chosen theoretical framework of activity theory and the thematic analysis approach, were regarded as useful in obtaining an understanding of the concept of using gamification as a teaching strategy for fostering school students' development of 21st century skills and the complexity of developing smart learning ecosystems. The first recommendation for future research is to not only expand the numbers of participants, but also conduct more designed-based research investigating new teaching strategies and their effect on school students' motivation and engagement for teaching and learning in schools. Along with this, more research on how to connect schools and universities to the surrounding society would be helpful. This would perhaps add other perspectives and broaden the understanding of what can

be included when developing smart learning ecosystems for the future of education systems.

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