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Augmented reality and gamification in higher education

Designing mobile interaction to enhance students' intrinsic motivation and learning

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Författare

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Titel

Förstärkt verklighet och spelifiering inom högre utbildning: Design av mobilinteraktion för att stärka studenters intrinsiska motivation och lärande

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Sammanfattning

Framväxten av förstärkt verklighet och gamification inom högre utbildning har fått betydande relevans på grund av dess beprövade användbarhet i lärandemiljöer. Tidigare forskning har undersökt dessa tekniker separat vilket visat lovande resultat, däremot vet man mindre om effekten av att kombinera förstärkt verklighet med spelifiering i högre utbildning. Denna artikel syftar till att konceptualisera, designa och utvärdera effekterna av förstärkt verklighet och spelifiering på studenters intrinsiska motivation och lärande vid användning av kurslitteratur. Resultaten från ett webbaserat experiment med 95 studenter visar att användningen av förstärkt verklighet ökar studenternas intrinsiska motivation i jämförelse med förekommande arbetssätt som digitalt föreläsningsmaterial. Kombinationen av förstärkt verklighet och spelifiering visade ingen effekt på studenternas intrinsiska motivation eller lärande. Resultaten kan utgöra grund för ytterligare forskning om spelifiering i högre utbildning och stödja författare vid utformningen av förstärkt verklighet i framtida kurslitteratur.

Ämnesord

förstärkt verklighet, spelifiering, högre utbildning, kurslitteratur, konceptdriven designforskning

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Title

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Abstract

The emergence of augmented reality (AR) and gamification in higher education has gained significant relevance by virtue of their demonstrated usefulness in learning spaces. Prior research has examined these technologies separately and shown promising results, but less is known about the impact of combining AR and gamification in higher education. This article aims to conceptualize, design, and evaluate the effects of AR and gamification on students' intrinsic motivation and learning with physical course literature. The results from a web - based experiment involving 95 students demonstrate that using AR enhances students' intrinsic motivation compared to conventional methods such as reading lecture notes. However, the combination of AR and gamification did not influence students' intrinsic motivation or learning. The findings could serve as a basis to further gamification in higher education and may support authors in the design of AR in future course literature.

Keywords

augmented reality, gamification, higher education, course literature, concept-driven design research

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1. Introduction

Augmented reality (AR) is an emerging form of experience representing a combination of digital technologies that produce and display digital content over a physical environment (Fidan & Tuncel, 2018; Fuchsova & Korenova, 2019; Tzima et al., 2019). AR could be defined as a system that fulfills three essential features: real and virtual combination, real-time interaction, and three-dimensional recording (Wu et al., 2013). In other words, it is a collection of different technologies that operate in combination to enhance the user's perception of the physical world through virtual information (Alonso-Rosa et al., 2020; Lebeck et al., 2017).

The progress of the current COVID-19 pandemic has led to the increasingly leveraging of AR solutions in classrooms and remote-learning environments in higher education (Nesenbergs et al., 2021). By layering virtual information over the physical environment, AR has demonstrated the potential to enhance individuals' engagement and learning experience in educational tasks (Chang, Hu, et al., 2019). The digital markups in AR let users perceive the physical world with added digital data as a single, seamless environment, which has shown to improve individuals' knowledge and understanding of what is happening around them (Fernandez, 2017; Singhal et al., 2012; Yuen et al., 2011).

Technological advances have raised the boundaries of the traditional classroom, and AR is one example of a new type of innovation in higher education (Sáez-López et al., 2020). It mainly provides students with new interaction possibilities that focus students' presence and attention (Chang, Chen, et al., 2019; Chang, Hu, et al., 2019). Previous research has found that using AR with physical course literature could deepen students' learning and knowledge, for example, in biology (Walker et al., 2017). Using AR technology for physical course literature provides students with a virtual layer that could make the educational setting more productive, enjoyable and interactive, while improving students' motivation and ability to understand complex theories (Lee, 2012; Vallera, 2019).

AR has also positively impacted students' motivation and performance since it provides them with a new form of social interactivity, connectivity, and context-sensitivity (Nincarean et al., 2013). With the help of a computer or a mobile screen, AR can improve a student's environment, allowing them to interact and visualize theory and concepts that are difficult to understand (Martín-Gutiérrez et al., 2015). Motivation in the context of learning is strongly correlated with learning effectiveness. Obtaining strong encouragement throughout tasks allows students to keep focus for a longer time, resulting in better and efficient learning (Chang, Hu, et al., 2019). Motivation could broadly be grouped into two categories: *intrinsic* and *extrinsic*. Intrinsic motivation refers to behavior that is driven by internal rewards or activities that are alluring or entertaining. In contrast, extrinsic motivation refers to behavior or engagement in activities to achieve external rewards, for instance, money, fame, grades, and praise (Cerasoli et al., 2014; Legault, 2016; Ryan & Deci, 2000).

When students read physical course literature, they run primarily by an external motivation to achieve a separable outcome (e.g., getting good grades and approval from the teacher) (Li & Wen, 2019). Generally, both external and internal motivation is seen as valuable in educational contexts. However, intrinsic motivation is regarded as preferable and more helpful in the learning process because it represents an activity's engagement for one's own sake (Legault, 2016; Lens & Rand, 2000; Liu et al., 2019). Implementing AR as a way of interacting with physical course literature could increase attention, satisfaction, and learning motivation (Khan et al., 2019).

In recent years, one way to promote student motivation and performance in education is through gamification (Perry, 2015). The concept of gamification is commonly defined as using "game design elements in a non-game context" to motivate participation (Deterding et al., 2011). The idea of gamification is to use game design elements to make services and activities more fun by offering meaningful choices, feedback, and autonomy (Nicholson, 2012). The benefits of gamification in higher education are increased motivation, overall better performance, and consistent class participation. Implementing gamification in higher education can make students more engaged in the learning process, resulting in better understanding and learning in class and on exams (Campillo-Ferrer et al., 2020). In higher education, gamified solutions have demonstrated positive effects on learning outcomes (Connolly et al., 2011; Song et al., 2018; Wang & Lieberoth, 2016).

While previous research has mainly focused on augmented reality and gamification separately, they have more seldom been studied in combination within higher education. Based on the previous reasoning, this article aims to conceptualize, design, and evaluate how a combination of augmented reality and gamification could be used to enhance students' intrinsic motivation and learning with physical course literature in higher education. The proposed research focuses on the area of web development with specific reference to color theory and the color system hue, saturation, lightness (HSL). The reasoning for this is that prior studies have identified that theoretical concepts in web development are experienced as complicated, difficult to understand, and could lead to lack of motivation among students (Faraon et al., 2020; Gomes et al., 2012; Watson & Li, 2014). Conversely, this article is guided by the following question: *How could augmented reality and gamification be conceptualized, designed, and evaluated to enhance students' intrinsic motivation and learning with physical course literature about web development in higher education?* The concept-driven design research approach by Stolterman and Wiberg (2010) will be used to address the research question and the methodology section will further this approach.

The following section presents a theoretical review of AR, gamification and factors related to learning experiences. Following this, the methodology is described to focus on the concept-driven design research approach and how it was used to evaluate AR and gamification in higher education. The reader is then presented with the results and corresponding analysis. Based on the results, a revised prototype is elaborated and contextualized. The final section concludes with a discussion of the results in relation to prior research and provides suggestions for future work.

2. Background

2.1 Augmented reality

Augmented reality (AR) is an emerging technology that creates a virtual layer in which digital and physical objects can interact through wearable technologies or head-mounted displays (Fidan & Tuncel, 2018; Fuchsova & Korenova, 2019; Tzima et al., 2019). The term “augmented reality” was first coined in 1990 by developers Tom Caudell and David Mizell, who produced an augmented reality system that could indicate potential drilling holes in an aircraft fuselage (Rese et al., 2017).

The use of AR technology has been limited due to large and inaccessible wearable technology. However, more user-friendly and portable hardware has become available over the past few decades. The accuracy of registration, image quality, and device size has reached a satisfactory level, leading to the rapid adoption of AR technology (Dey et al., 2018). Even if AR has been around for decades (Jingen Liang & Elliot, 2021), the market for the technology, both hardware and software, is still dynamic and in a formation stage. The forecast concerning the demand for AR indicates that the technology will expand and develop for different fields, companies, and individuals (Davydov & Riabovol, 2019).

By using AR technology, people can interact with virtual content in new ways by enriching physical environments with virtual objects and information (e.g., sound, text, video, 3D objects). Through a design that fulfills three essential features: *real and virtual combination*, *real-time interaction*, and *three-dimensional recording*, AR could be perceived as a mixture of technologies (monitoring properties, handheld devices, and display systems) that enhance users’ perception of the physical world (Fidan & Tuncel, 2018; Wu et al., 2013). Augmented reality applications capture user input from the user environment like video, audio, or depth sensor data, and overlay output such as visual, audio, or haptic feedback, to seamlessly add value and enhance interaction with the physical reality (Alonso-Rosa et al., 2020; Lebeck et al., 2017).

AR technology has been used in various fields, for example, in medicine (e.g., planning surgery and patient treatment) (Eckert et al., 2019), culture (e.g., museums and art galleries) (tom Dieck et al., 2018), tourism (e.g., providing people with rich and engaging content for destinations) (Cranmer et al., 2020), retail (e.g., enhancing customers' shopping experience by creating a three-dimensional augmented experience) (Poushneh, 2018), logistics (e.g., assisting for the planning of logistics systems) (Wang et al., 2020), and education (e.g., offering 3D visualizations to contribute with visual context to literature) (Khan et al., 2019).

Although AR has proven to be useful and has contributed to positive outcomes in previously mentioned fields, there are also disadvantages with the technology. For instance, when Pokémon Go launched in 2016, it brought an immense interest in the opportunities of AR (Rauschnabel et al., 2017). Even if Pokémon Go contributed to increased physical activity, it also harmed people in traffic accidents and muggings as a result of users being distracted by the use of AR in the application (Sharma & Vassiliou, 2016) and immersed while they are present in a physical environment (Rauschnabel et al., 2017).

While the technology for AR is developing rapidly, there are also current limitations with it. One of them is the display size, which is relatively small compared to virtual reality (VR) applications (Lovreglio & Kinateder, 2020). Current AR applications often struggle with two concerns: tracking and recognizing (Lovreglio & Kinateder, 2020). The AR application needs to know where the device and user are as well as track their movements. For this purpose, the technology needs to rely on external or internal sensors, which both have their limitations. For example, the technology for internal sensors is still limited in its refresh rate and range, restricting it to static indoor use (Lovreglio & Kinateder, 2020). The cost of developing and maintaining AR applications is also a current disadvantage (Li & Shang, 2019; Lovreglio & Kinateder, 2020). Designing and creating virtual scenarios is complex and requires expertise. Since AR is also rapidly developing, the technology needs constant updates to stay up-to-date (Lovreglio & Kinateder, 2020).

Furthermore, the social and ethical problems that arise due to the rapid development of AR cannot be overlooked. As with previous emerging technologies, AR systems have a wide range of ethical areas of interest that could have consequences at both the societal and the individual level (De Guzman et al., 2020; Neely, 2019). For example, privacy (e.g., an AR channel's ability to access resources outside the browser sandbox presents privacy risks to its users), deception (e.g., developers may deliver bogus information to users by altering the AR content), and ownership and property (e.g., depending on where the AR is used, for instance in the public or private area). The technology presents novel concerns about the restrictions on gathering rights, ownership, and intellectual property security (McPherson et al., 2015; Roesner et al., 2014; Wolf et al., 2016).

Despite the current limitations and ethical concerns of AR technology, it has proven to positively impact motivation and performance, for instance, in the area of education as it provides a new form of social interaction, connectivity, and context-sensitivity (Di Serio et al., 2013; Erbas & Demirer, 2019; Khan et al., 2019). AR has also demonstrated that it could support students to gain more cognitive, affective, and participatory knowledge (Mei & Yang, 2019).

Although considerable research has been devoted to demonstrating how augmented reality could enhance learning in several academic disciplines (e.g., biology, health science, engineering) (Arulanand et al., 2020; Moro et al., 2017; Weng et al., 2020), little attention has been paid to how it may be combined with other technologies to enhance students' intrinsic motivation and learning in the area of web development in higher education. For this reason, the next section will describe and illuminate gamification as a potential that could be used to enhance students' intrinsic motivation through progress mechanics (e.g., points, badges, leaderboards) and game principles (e.g., interactivity, feedback).

2.2 Gamification

Gamification could broadly be defined as the application of game-design elements and mechanisms in a non-gaming context (Deterding et al., 2011; Passalacqua et al., 2020). Others have defined gamification as "a process of enhancing a service with affordances for gameful experiences to support users' overall value creation" (Huotari & Hamari, 2017, p. 25). Compared to the first definition, which focuses on the methods and mechanics, the latter highlights the goal of gamification, i.e., the experiences that it attempts to give rise to through "a process in which the 'gamifier' is attempting to increase the likelihood of the emergence of gameful experiences by imbuing the service with affordances for that purpose (be they badges, points or more implicit cues)" (Huotari & Hamari, 2017, p. 25).

Game-design elements have been discussed amongst different subdisciplines of game science (Landers et al., 2018). From the perspective of human-computer interaction, game-design elements are defined as distinctive elements to games (Deterding et al., 2011). Game developers describe game-design elements as mechanics (i.e., the rules or components), dynamics (i.e., the behavior of the player with the mechanics), and aesthetics (i.e., the emotional responses of the player) (Landers et al., 2018). Common game-design elements associated with gamification are points, awards, ranks, leaderboards, stories, and feedback (Deterding et al., 2011). The most fundamental and common element is points, which have a notional value and contribute to feedback and rewards. Awards or badges usually serve as a secondary reward system in the form of a visual representation of achievement. Rank systems and leaderboards demonstrate the usernames in order, together with a display of points or achieved goals which indicates the users' progress (Groening & Binnewies, 2019).

The term "gamification" did not enter the mainstream vocabulary until 2010 (Dichev & Dicheva, 2017). Since then, gamification has increasingly attracted interest, and several areas have adopted it to induce motivation, both intrinsic and extrinsic, for diverse activities (Koivisto & Hamari, 2019). Intrinsic motivation could be characterized as behavior driven by long-term internal rewards or engaging and entertaining activities (e.g., self-satisfaction, curiosity, interest). Extrinsic motivation may be described as behavior driven by short-term achievement for external rewards (e.g., money, fame, grades) (Ryan & Deci, 2000). While intrinsic and extrinsic motivation has often been studied separately in the context of gamification, researchers argue that they both must be considered to promote behavior change (Cerasoli et al., 2014; Kingsley & Grabner-Hagen, 2018; Zichermann & Cunningham, 2011).

Despite that a growing body of literature has investigated gamification and intrinsic motivation, the research findings are mixed. On the one hand, some studies found intrinsic motivation to be a good predictor of user satisfaction, user continuance, and perceived efficiency (Bormann & Greitemeyer, 2015; Peng et al., 2012; van Roy & Zaman, 2018). Research has also shown that implementing game mechanisms, such as points and leaderboards, could foster intrinsic motivation (Xi & Hamari, 2019). On the other, researchers have identified that implementing the mentioned game mechanisms could decrease intrinsic motivation (Ahn et al., 2014; Deci et al., 2001; Hanus & Fox, 2015) or not have any effect on intrinsic motivation (Mekler et al., 2017; Mitchell et al., 2020).

Moreover, research has shown that gamification could enhance individuals' extrinsic motivation (Ferriz-Valero et al., 2020; Groening & Binnewies, 2019; Mekler et al., 2017; Razali et al., 2020). However, the design of the elements of extrinsic incentives should be carefully considered so that individuals do not feel controlled or pressured (Cerasoli et al., 2014). If the extrinsic incentives make the individual feel controlled or pressured, it is possible that the will for performing a task decrease. Therefore, it is important to include positive feedback because this type of extrinsic incentive positively enhances intrinsic motivation (Wijsman et al., 2019; Woolley & Fishbach, 2018).

Gamification has demonstrated potential in learning processes. Research shows that using gamified quizzes with points and leaderboards could positively affect intrinsic motivation and social relatedness (Sailer & Sailer, 2021). Other research has indicated that using elements such as fantasy (e.g., creating images that do not exist in the physical world allows users to interact without fear of real-life consequences)

(Garris et al., 2002), representation (e.g., using visuals and graphics to represent concepts and provide information) (Doney, 2019), and sensory stimuli (e.g., using audio or visuals for performance feedback) (Tinedi et al., 2018) may be beneficial in the learning process and increase both intrinsic and extrinsic motivation (Oliver, 2017; Tinedi et al., 2018; Wilson et al., 2009).

Furthermore, game-design elements such as challenge (Carenys et al., 2017), mystery (e.g., creating a gap between the known and unknown to arouse curiosity within the user) (Tinedi et al., 2018; Wilson et al., 2009), assessment (e.g., providing a user with feedback to inform progress) (Oliver, 2017; Wilson et al., 2009) and control (e.g., giving a user to affect an outcome) (Guillén-Nieto & Alesón-Carbonell, 2012; Kikot et al., 2014) have demonstrated to enhance students' learning experiences and make them feel excited about learning (Oliver, 2017; Wilson et al., 2009).

Although gamification has proven to be a potential for improving motivation and learning, some concerns need to be considered. For instance, gamification may fail to engage users and lead to participation issues. It means that a gamification proposal that is not seamlessly designed in a unified way with existing procedures and tools may not be successful in the long term (Pedreira et al., 2015). Another possible concern is that reward responses may encourage users to behave in a desired way only when compensated. Hence, the gamification layer may overwhelm the main activity and obscure the activity itself (Knaving & Björk, 2013). In gamified weight monitoring systems, users could cheat by consistently understating the amount of food they eat in relation to the points they are allocating while claiming to follow the system's rules (Knaving & Björk, 2013). Prior studies have also shown that the engagement that gamification creates often decreases with time. One explanation behind this is that providing novel information helps to maintain interest in gamification, but if such information is scarce, this may pose a challenge to preserve its long-term use (Hanus & Fox, 2015; Koivisto & Hamari, 2014; Mollick & Rothbard, 2013).

Despite the mentioned limitations, gamification has demonstrated positive effects on learning experiences and motivation in higher education (Ferriz-Valero et al., 2020; Santos-Villalba et al., 2020). The following section will examine the current state-of-art concerning the use of augmented reality and gamification in higher education to theoretically underpin and prescribe a design concept with principles, concepts, views, and characteristics that may enhance students' motivation and learning.

2.3 Augmented reality and gamification in higher education

The emergence of augmented reality (AR) and gamification in higher education has gained significant relevance thanks to their demonstrated usefulness in learning spaces (e.g., increased student engagement, interactivity, enjoyment, motivation, interest in and commitment to a subject) (Ferriz-Valero et al., 2020; Moro et al., 2017; Santos-Villalba et al., 2020; Weng et al., 2020). While current studies have investigated these technologies separately, there is limited research examining AR and gamification as a combined design in a higher education context.

One study explored the use of AR and gamification in environmental education at Chinese universities (Mei & Yang, 2019). By using a geolocation-based game, students were allowed to follow in-app clues to reach pre-determined destinations. Once the students arrived, they received interactive and informative digital content about the campus environment that aimed to increase their environmental knowledge and awareness of environmental issues. At the same time, students were provided with English questions about biodiversity and sustainable lifestyle. The purpose of the game design was to meet the following two learning objectives: (1) Direct students' attention to the environmental aspects in their campus life instead of the technology itself and; (2) master English expressions related to the campus environment (Mei & Yang, 2019). The results demonstrated that the combined strategy could engage students in environmental awareness and knowledge about subject content while contributing to students' enhanced learning experience and developing students' environmental understanding and reflective thinking skills (Mei & Yang, 2019).

Other research has shown that AR in higher education can increase students' motivation for learning and contribute to improved academic achievement (Lee, 2012; Vallera, 2019; Walker et al., 2017). For example, students in fashion education were provided with the opportunity to use AR technology through their smartphones to deepen their design skills with video and audio embedded in course literature. The findings showed that the added value of AR in a learning environment strengthened students' functional, aesthetic and creative skills in fashion design. The researchers argued that AR does not isolate students from the physical world. Instead, it contributed with interactive technology that could raise students' curiosity and boost their will to explore creative paths (Elfeky & Elbyaly, 2021).

Similar to previous research, AR technology has been adopted to examine how it could impact bioscience students' understanding of structural biology. 3D models were used so students could get a visual representation of protein molecules and provide a better understanding of their structures. This teaching approach was found to be engaging and enriching for students' learning process and outcomes (Reeves et al., 2021).

When designing an effective AR learning tool, it is essential to create a sustainable link between AR and higher education since the technology must be established with a cognitive approach. It is crucial to integrate an appropriate combination of visual objects and words that support each other so that students can gain a better understanding of what they are learning (Abad-Segura et al., 2020). Research in gamification has shown significant benefits in higher education, for example, it enhances students' engagement, motivation, concentration, and enjoyment (Ferriz-Valero et al., 2020; Santos-Villalba et al., 2020; Wang & Lieberoth, 2016). One of the compelling reasons to 'gamify' a classroom is to increase student engagement (Canhoto & Murphy, 2016; Veltsos, 2017), encourage students to pursue their own goals, and engage in challenging tasks (Huang & Hew, 2018).

However, previous research has presented gamification efforts in higher education with mixed results (Dicheva et al., 2015; Seaborn & Fels, 2015). A potential reason for these results is different contextual factors, for example, player qualities, the design of the gamified system, and the match between the motivational affordances embedded in the system and users' overall goals and interests (Hamari & Koivisto, 2015; Hamari et al., 2014). Therefore, to design an effective gamification tool, it is necessary to understand the implementation context and students' needs (Mora Cerreño et al., 2015).

Previous findings have shown that whether or not students get motivated and engaged by gamification is highly related to the interaction level between games' components (e.g., design, layout, materials, and tasks) (Deif, 2017). The gamification design needs to avoid abstract and complex tasks and focus on concrete, achievable tasks to motivate students and increase their satisfaction during the learning process (Deif, 2017). It is also essential to provide immediate feedback through awarding points for the correct answer since it can contribute to the learning process (Sailer & Sailer, 2021). To achieve this, perceived usefulness and the attitudes towards using gamification constructs will all need to be considered together to predict student engagement (Rahman et al., 2018).

Looking specifically at higher education, little research has been focused on how AR and gamification could be used to enhance students' motivation and learning. However, closely related research in computer science has utilized gamification to enhance students' motivation (Ahmad et al., 2020). In the study, the following game elements were used: points (the most fundamental component to enhance motivation), badges (to signify the student's achievement to acknowledge efforts), rewards (incentives the student gets after a challenging task to enhance self-satisfaction), levels (to indicate the student's process), ranks (used as milestones to show how well the student is progressing) and leaderboards (to display ranks of students for social comparison). The results of the study present gamification to be an effective tool in teaching since students' learning outcomes and satisfaction was found to be affected positively by the implementation of the mentioned game elements (Ahmad et al., 2020).

In contrast to previous results, the use of badges has produced both positive and negative effects. In one study, digital badges were used in a programming course to investigate their effects on motivation, social recognition, and encourage student attendance. The results indicated that the use of badges did not increase students' intrinsic motivation. However, the survey and data showed that badges were received positively. The researchers argue that the challenge was to sustain rather than increase motivation throughout the whole semester (Facey-Shaw et al., 2020). In another study, Zhou et al. (2019) reported increased participation with badge use and recommended focusing on design rather than competition to motivate learners. Empowering students to control their learning is crucial to use badges as a motivational element (Davis & Klein, 2015).

3. Methodological approach

3.1 Concept-driven design research

This article adopted the concept-driven design research methodology proposed by Stolterman and Wiberg (2010) to conceptualize AR and gamification as a combined artifact for educational purposes. The method aims to demonstrate a theoretical concept in a concrete design and is based on the following three principles:

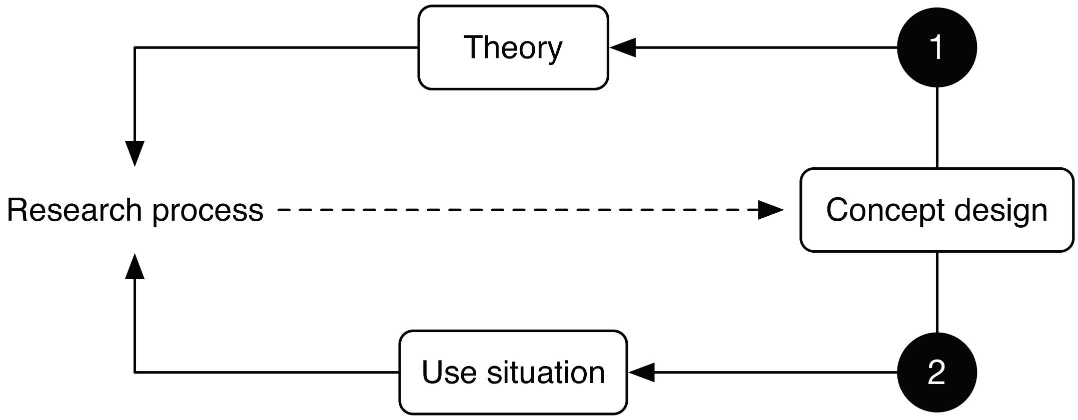
1. The starting point is conceptual/theoretical rather than empirical.
2. The research promotes conceptual and theoretical explorations through practical design and the development of artifacts.
3. The final design is then optimized to a specific idea, concept, or theory rather than to a particular problem, user, or use in a particular context.

The process of the concept-driven design approach is illustrated in Figure 1. Stolterman and Wiberg (2010) define this approach as having a conceptual and theoretical point of departure rather than an empirical one (Arrow 1). Conceptual and theoretical explorations are aimed to produce a design concept that could support a futuristic use situation (Arrow 2).

The methodological approach is based on seven activities: *concept generation, concept exploration, internal concept critique, design of artifacts, external design critique, concept revisited, and concept contextualization*. Each of these activities contributes to the concept generation process and will be further described in the following. The first activity in the methodological approach is *concept generation*, which aims to develop new concepts based on previous research. In this activity, it is essential to find unexpected and unique qualities with the concept. Stolterman and

Wiberg (2010) point out that "*a new concept design must provide something new, either in the way it combines earlier qualities or in the way it manifests a whole*" (p. 110). The idea is to demonstrate that a concept is unique by using distinct methods such as metaphors and theories from other design fields and combining new and old ideas into one. This stage provides the researcher with a diversity of ideas that helps develop a variety of potential concepts.

Figure 1. *The process of the concept-driven design research approach in relation to theory and use situation, adopted from Stolterman and Wiberg (2010, p. 101).*



The second activity is *concept exploration* that goes deeper into the research process by exploring ideas and working practically with materials as well as the content. The purpose is not to refine or test established ideas but instead exploring new design spaces that lead to undiscovered areas and new ideas that challenge contemporary theoretical understandings (Stolterman & Wiberg, 2010).

The next activity is *internal concept critique* and involves a process where a design with associated concepts is theoretically underpinned. It is essential to evaluate a design concept through sketches and prototypes to visualize what makes the proposed design concept unique. Stolterman and Wiberg (2010) argue that "*the success of this phase relies on the identification and establishment of (a) the uniqueness of the chosen core concepts and (b) to what extent the concepts relate to existing theory, and (c) how well these concepts can be clearly expressed in a concrete design*" (p. 110). To succeed in this activity, the above factors need to be infused into and manifested by the proposed concept.

Following the internal critique is the *design of artifacts*. In this activity, the essential design concept should be carved out and expressed in a concrete artifact. The design concept becomes an actual artifact and could be described as "*a concrete manifested composition that incorporates the concept design as a 'whole'*"

(Stolterman & Wiberg, 2010, p. 111). It means that theory and craft–the making of the artifact–will merge to manifest a complete concept.

In the subsequent activity, the *external design critique*, the concept is presented to external participants to highlight and examine their experiences and thoughts of it. This activity aims to evaluate "*the idea, the concept, and the inherent theoretical principles that the design manifests*" (Stolterman & Wiberg, 2010, p. 111). Previous research adopting the concept-driven design research approach has demonstrated that either a qualitative (Eliasson, 2013; Johansson & Wiberg, 2012) or a quantitative (e.g., Faraon, 2018) approach could be suitable for the external design critique. The collected data could then empirically underpin and theoretically further the proposed concept in the next activity.

Based on the external design critique, the *concept revisited* activity addresses the provided feedback and guides additional design revisions. The goal is to determine how a concept could empirically and theoretically be advanced by deciding whether it has flaws and imperfections. It is essential to distinguish between general thoughts and personal opinions. General ideas are lifted, while personal views do not weigh as heavily. Furthermore, a distinction is made between whether the thoughts should be included in the concept or be reported as future research (Stolterman & Wiberg, 2010).

In the last activity, *concept contextualization* places the proposed concept in the current body of concepts and theory. Stolterman and Wiberg (2010) emphasize that this activity is "*crucial for the knowledge-gaining process of conducting concept-driven interaction design research and an important step in order to contribute to the current body of knowledge*" (p. 111). The concept is evaluated in relation to previous research to highlight its uniqueness and contributions to the field of study. In the following section, the seven mentioned activities associated with the concept-driven design research approach are elaborated by how they have been applied in this article.

3.2 Application of concept-driven design research

This article applies the concept-driven design research approach to generate a design concept that proposes how AR and gamification could be conceptualized and designed in combination to enhance students' intrinsic motivation and learning with physical course literature about web development in higher education. Based on the seven activities described in the previous section, this part will focus on how each activity was applied in the current work to elaborate the concept of AR and gamification.

The first activity of the method focuses on *concept generation*, which is an important activity for establishing a theoretical foundation for this study. The theoretical foundation consisted of previously established research related to (1) augmented reality (AR), (2) gamification, and (3) state of the art of AR and gamification higher education. AR was examined based on its advantages and disadvantages as well as its impact on learning in educational contexts. Gamification, which has been previously studied with regards to motivation, was used as a theoretical lens because of its intrinsic and extrinsic impact as well as for its game elements. Lastly, the combination of AR and gamification in the context of higher education was studied to gain an understanding of the current state of the art.

The reasoning for this is that prior studies have identified that theoretical concepts in web development are experienced as complicated, difficult to understand, and could lead to lack of motivation among students

Based on the results in previous research identifying theoretical concepts in web development being complicated, difficult to understand, and could lead to a lack of motivation among students (Faraon et al., 2020; Gomes et al., 2012; Watson & Li, 2014), ideas were identified for a potential design concept for the area of color theory. More specifically, the topic that emerged was color theory in higher education, specifically a color system referred to as hue saturation lightness (HSL). *Hue* could be described as a visual impression of the colors red, yellow, green, and blue, or a combination of two of them. *Saturation* indicates the amount of grey in a color, which can provide a feeling of a colorful tone. Finally, *lightness* concerns the amount of black in a color and controls the lightness or darkness. To study and learn the HSL color system, three range sliders were conceptualized to vary each of the three parts of HSL.

During the *concept exploration*, the aim was to seek and communicate ideas based on the findings in the theoretical background to explore new possibilities for the concept. In this activity, exploring possibilities contributed to a broader understanding of how AR and gamification could be implemented for physical course literature about web development. Through the JavaScript-based A-Frame framework (aframe.io), the concept, which was identified during concept generation, was designed in the form of a prototype. The interaction consisted of users being able to point a mobile camera at a written page, which mimicked physical course literature about web development, to obtain augmented reality and gamification of the HSL color system. Since smartphone devices were chosen for this study, it was essential to explore how the prototype could be designed to fit a mobile screen. During the exploration, it emerged that three range sliders that could control hue, saturation, and lightness were suitable for user interaction and to promote an interactive learning experience. Further, a quiz was implemented to infuse the prototype with a gamification component. The quiz included gamification elements such as points, badge, progress bar, visual and audio feedback to enhance students' motivation and learning (Groening & Binnewies, 2019; Tinedi et al., 2018; Wijsman et al., 2019; Woolley & Fishbach, 2018; Xi & Hamari, 2019).

In the activity of *internal concept critique*, the focus was to define the strengths and weaknesses of the concept based on previous research. The concept was evaluated against existing approaches and tools to examine its uniqueness (e.g., evaluating and comparing the design concept in relationship to existing AR concepts for higher education). The aim was to determine how well the concept embodied the theoretical underpinnings when designing AR and gamification for higher education. For example, it was crucial to integrate a combination of visual objects and words that support each other for students to gain a better understanding of what they are learning (Abad-Segura et al., 2020). It was also necessary to understand the implementation context and students' needs to design an effective gamification tool (Mora Cerreño et al., 2015). The gamification design needed to avoid abstract and complex tasks and instead focus on concrete and achievable tasks to motivate students and increase their satisfaction during the learning process (Deif, 2017). These findings, emerging from previous research, were carefully considered in crafting the design.

Further, this activity also allowed a critical review of the concept's concreteness and revealed that specific parts of the design needed revision. The first revision concerned the length of the audio feedback that had to be shortened from two seconds to one to avoid delayed or absent feedback. Moreover, a feature was added to help users see which answer was right and wrong during the quiz to boost the learning process (Sailer & Sailer, 2021). Regarding the quiz, the number of questions was increased from only theoretical to a mix of multiple-choice, color matching, and color control questions to create a diverse set of questions covering both theoretical and practical tasks (i.e., multiple-choice, matching, estimation).

The subsequent activity, *design of artifacts*, focused on designing an artifact that theoretically supports and underpins the choice of design (Stolterman & Wiberg, 2010). The design concept is based on how AR and gamification could be designed for physical course literature about web development in higher education. The implementation of AR in the form of audio embedded in course literature is necessary for games to capture students' attention and increase their sense of autonomy, i.e., the ability to choose for oneself which activity to engage in, thereby increasing their intrinsic motivation (Tinedi et al., 2018). Moreover, 3D models have been used to give students a visual representation to engage and enrich the learning process (Reeves et al., 2021). Gamification has shown promising results in the context of learning and research indicates that using gamified quizzes with points and leaderboards (Sailer & Sailer, 2021), badges (Davis & Klein, 2015; Zhou et al., 2019), ranks (Ahmad et al., 2020; Groening & Binnewies, 2019), levels (Ahmad et al., 2020), feedback (Wijsman et al., 2019; Woolley & Fishbach, 2018), and audio (Tinedi et al., 2018) could have positive effects on intrinsic motivation and social relatedness.

The prototype used for this study is based on AR and included two pages of color theory notes. The first page consisted of text concerning the HSL (hue, saturation, and lightness) color system and an illustration that provides context to the theoretical text.

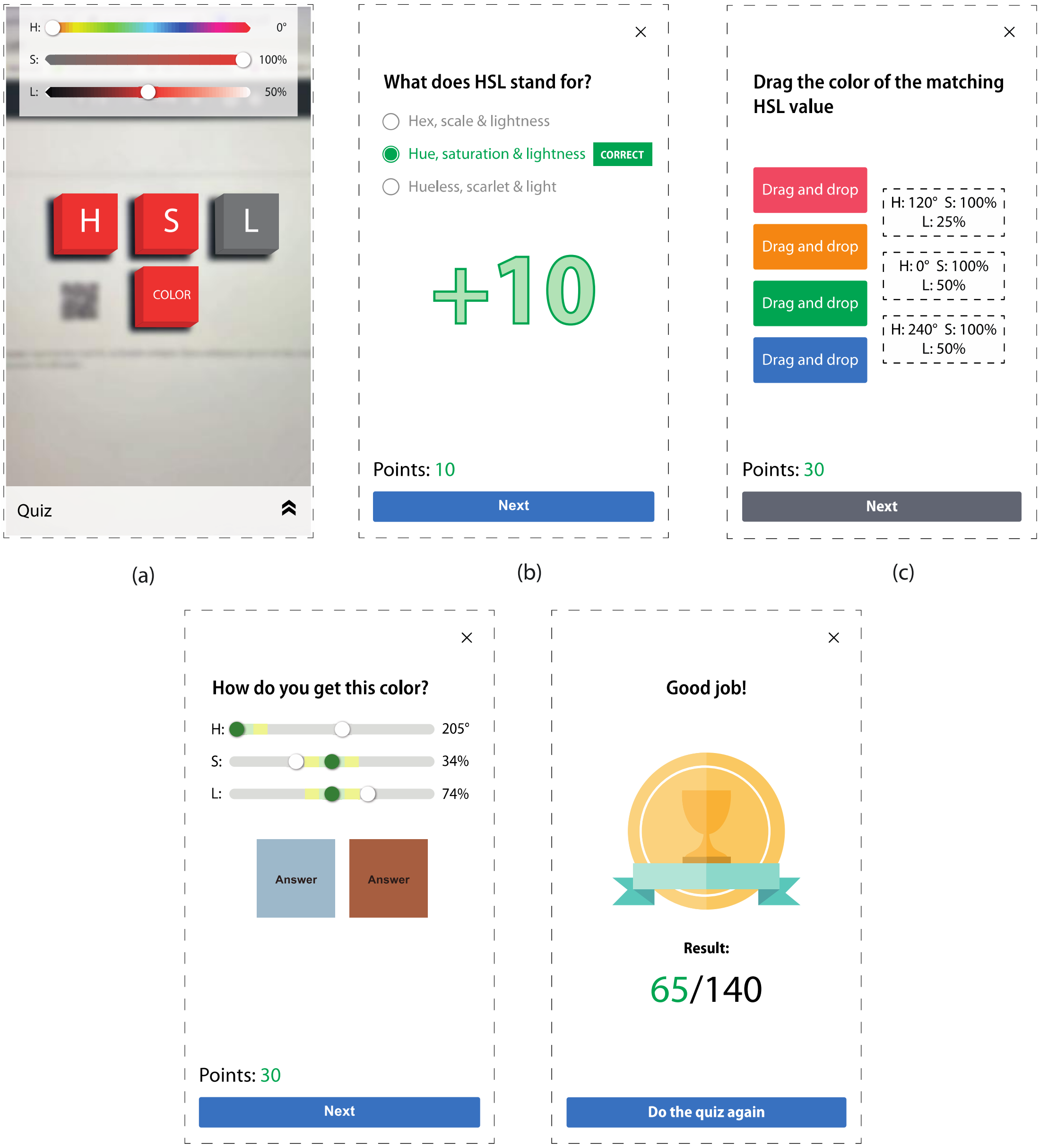
The second page consisted of four small markers and a two-dimensional QR-code. The prototype was implemented on paper to simulate physical course literature about web development in higher education, where students could interact with the material. To open the prototype on a mobile device, users had to scan the QR-code with their mobile camera. Four three-dimensional (3D) cubes were formed along with three color range sliders upon opening the prototype and directing the camera at the markers. The three range sliders were given the names H, S, and L. The color range sliders allowed users to swipe left and right, which provided them with the opportunity to explore the meaning of each of the three HSL components. Along with the color range sliders and the 3D cubes, a quiz could be found at the bottom of the AR prototype.

The quiz consisted of 12 questions based on the color theory notes. The first half of the quiz consists of five theoretical questions from the lecture notes where it is possible to earn 10 points for each correct answer. The second half of the quiz was more practical and consisted of questions characterized as color matching and estimating the presented colors using the range sliders. Each color matching question presented four boxes of color alternatives and three boxes of different HSL values. It was possible to drag and drop each color to a HSL value and earn 5 points for every correct answer. Each color estimation question presented a color and three range sliders consisting of hue, saturation, and lightness. It was then possible to drag the range sliders to get as close to the given color. When the value of each range slider was chosen, the answers could be validated by pressing a control button to see the color of the selected values and how close/far their values were from the correct ones. Three points would be rewarded if the selected values were within +/- 15% of the correct ones and an additional two points if they were within +/- 7.5%. The purpose of the percentage range was to motivate participants for understanding rather than penalizing them for not knowing.

Upon completion of the quiz, a screen was presented that included the total score, a gained badge, and an opportunity to retake the quiz. Different feedback would be given for all questions and this depended on whether a correct or an incorrect answer was chosen. Correct answers were presented in green color with an audio tone and the number of points being briefly visible on the screen. Incorrect answers were presented in red color with no audio feedback or earned points. Based on the theoretical underpinnings and the previous reasoning, a design concept was crafted according to Figure 2.

The first screen (a) of the design concept illustrates the AR simulation, which is visualized by four cubes that define the values for HSL. The fourth cube, "color," presents the resulting color formed by the HSL values. The second screen (b) represents the first step of the gamification quiz, where a user must choose an answer that corresponds to the presented question. The third screen (c) shows a matching question, where the user should drag and drop colors to match them with their corresponding HSL values. The fourth screen (d) shows an estimation question, where a user recreates a color by estimating its HSL values. The fifth screen (e) displays the final step of the quiz and includes a badge and the total score of the quiz.

Figure 2. *A theoretically underpinned design concept that combines AR and gamification with the aim to enhance students' intrinsic motivation and learning with physical course literature about web development in higher education.*



(a) (b) (c)

(d) (e)

In the activity of *external design critique* of the concept, the concept was used to design a working prototype of AR and gamification. Participants were randomly assigned to one of three groups. The first group evaluated lecture notes regarding the HSL color system. The second group evaluated lecture notes followed by the AR prototype. The third group evaluated the lecture notes, the AR prototype, and the gamification component. All three groups answered a questionnaire regarding their motivation and learning process when studying the color system HSL. During this activity, participants' thoughts of the concept and prototype, including advantages and disadvantages, were documented.

Based on the criticism that emerged in the previous activity and following the recommendations by Stolterman and Wiberg (2010), a *revision of the concep*t was made. The study results were analyzed and investigated to identify potential improvements of the design concept. The revised design concept integrated feedback from the *external design critique* and can be found in the results section.

Lastly, the *concept contextualization* activity remained, which took place when the concept was defined and evaluated in the AR prototype (Stolterman & Wiberg, 2010). This activity aimed to compare the revised concept with the current body of concepts and theory in the field of AR and gamification in higher education. The purpose is to appraise its contributions to previously accomplished work. All theory, insights, and observations obtained throughout the process were compiled to contribute to future concepts.

3.3 Research design

In contrast to prior research (Chiang et al., 2014; Gopalan et al., 2016; Khan et al., 2019; Solak & Cakir, 2015), this study applied a between-subjects web-based experiment to measure participants' motivation and learning experiences of the HSL color system through AR and gamification. Participants were pseudo-randomly assigned to one of three groups: (1) reading only lecture notes; (2) reading lecture notes followed by using an AR prototype and; (3) reading lecture notes followed by using an AR prototype with gamification, see Appendix A. Two unique QR codes were generated for the second and third groups to access the AR prototype that either excluded or included a gamification quiz.

3.4 Participants

A total of 114 participants studying in higher education were invited to the experiment. After processing the data for incomplete/missing values and outliers, 95 participants remained in the final dataset. A total of 70 percent of the remaining participants were females (n = 67). 28 percent were males (n = 27), and 2 percent did not want to disclose their gender (n = 1). Participants were between the ages of 20 and 53 (M = 26.48; SD = 5.69). Participants in the first group (lecture notes) consisted of 24 females and 10 males with an age range of 21-48 years (M = 27.79; SD = 6.20). Those in the second group (augmented reality) consisted of 18 females, 12 males, and 1 undisclosed and had an age range of 20-33 years (M = 24.84; SD = 3.05). Participants in the third group (augmented reality with gamification) consisted of 25 females and 5 males. Their age range was 21-53 years (M = 26.70; SD = 6.83).

Participants chose between participating anonymously and without compensation or compensated with a gift card worth $10, redeemable in a large chain of supermarkets, by providing their email address. The distribution of gift cards necessitated the partial waiver of anonymity. Because the evaluation area concerned students in higher education and due to the circumstances related to the COVID-19 pandemic, it was necessary to adopt the following criteria for participation in the experiment: studying at higher education, access to a smartphone, and an internet connection.

3.5 Materials and measures

The materials consisted of lecture notes and an AR prototype. All materials, measures, and appendices are available on the open science framework (OSF): https://osf.io/k96cw/. Depending on the experimental condition, a one- or two-page pdf covering the color system HSL was used as *lecture notes*; see Appendix A. The first page consisted of an introductory text of HSL and a figure illustrating the three parts of HSL. The second page included four markers that were used with the AR prototype and gamification component. Three markers were dedicated to the three parts of HSL, and the remaining marker was used to present the resulting color. A link to the AR prototype was embedded using a QR code.

The *AR prototype* either excluded or included the gamification component, depending on the experimental condition. The prototype was developed as a mobile web application and based on the A-Frame framework (aframe.io). While other frameworks were available, for example, TensorFlow (tensorflow.org/js), A-Frame was chosen due to its support of showing 3D models over markers. Markers could be described as rectangles with thick borders and a pattern on the inside. The pattern consisted of the letters “HSL” and the word “Color”, see Appendix A. The markers were generated using the AR Marker Training tool, which produced image files used in the lecture notes. The pattern ratio in the AR Marker Training tool was set to 50% to stabilize potential shaking of the 3D models in the AR prototype when viewed on a smartphone. The gamification component in the AR prototype consisted of 11 questions divided into three categories: multiple-choice (5), matching HSL values with colors (3), and estimating HSL values based on given colors (3). The answers for all questions were randomized, and the responses were saved in a database without any identifying data.

The measures used to assess participants' motivation and learning experiences were an online survey and learning analytics of gamification. The *online survey* consisted of two demographic items, three modified versions of the 36-item Instructional Materials Motivation Survey (IMMS), and six open-ended questions aimed at capturing participants' learning experiences of the AR prototype and the gamification component. The first two items collected age and gender (female, male, other).

The IMMS was developed to measure students' learning motivation based on the attention, relevance, confidence, and satisfaction (ARCS) model (Keller, 1987). It consists of 36 items divided into four subscales: attention (12 items), relevance (9 items), confidence (9 items), and satisfaction (6 items), see Appendix B for the IMMS and its scoring guide. The IMMS has been validated in previous research when assessing the impact of a particular technology on students' learning motivation (Di Serio et al., 2013), including the use of AR technology in educational contexts (Chiang et al., 2014; Di Serio et al., 2013; Gopalan et al., 2016; Solak & Cakir, 2015).

Three modified versions of the IMMS were used in the experiment and were judged on a Likert scale ranging from 1 (completely disagree) to 5 (completely agree). The first version was adapted to assess participants' motivation for the lecture notes (Cronbach's alpha = .87), the second version for the AR prototype (Cronbach's alpha = .95), and the third version for the AR prototype in combination with the gamification component (Cronbach's alpha = .93), see Appendix C-E. Cronbach's alpha showed a value of .85 or higher for all three measures, indicating satisfactory internal consistency reliability (Cronbach, 1951).

The purpose of the six open-ended questions was to assess participants' learning experiences (e.g., what difficulties did you experience with the prototype?). The qualitative data also served as feedback for the revision of the prototype. Finally, the experiment implemented *learning analytics* to provide insights into participants' comprehension of the lecture notes when using augmented reality with gamification. The quantitative data was anonymized and included non-identifiable data such as question responses, accuracy, and total score of the gamification quiz.

3.6 Procedure

Participants were invited through a learning management system and via Facebook to participate in the study. Participants who met the inclusion criteria, see section 3.4, were sent a welcome letter depending on which group they were randomized to, see section 3.3. The welcome letter included information concerning the purpose of the study, access information to the different types of learning materials (lecture notes, AR prototype, or AR prototype with a gamification quiz (see Appendix A), estimated length to complete the survey, and contact information to the authors. The three surveys, one for each group, were created using Qualtrics Research Core and included in the welcome letter. Upon opening the survey, participants were informed about the purpose of the study, instructions on what they would evaluate, and that it would take approximately 5-10 minutes to complete it. Upon completing the experiment, the data was exported from Qualtrics Research Core and imported to SPSS for further processing.

3.7 Ethical considerations

This study adhered to the four ethical requirements for research recommended by the Swedish Research Council (2017). The four requirements are *information*, *consent*, *confidentiality*, and *usage*. The participants were informed about the purpose of the study, the content of the experiment, and that participation was voluntary. Participants were further informed that they could at any time withdraw from the experiment. Consent from the participants was obtained by asking whether they agreed to participate in the experiment. The confidentiality requirement was achieved by only collecting demographic data about the participants, such as age and gender. Participants who chose to be compensated with a gift card worth $10, redeemable in a large chain of supermarkets, were asked to provide their email address. The distribution of gift cards necessitated the partial waiver of anonymity. Finally, the usage requirement meant that the study would only use the gathered data for scientific research. All data collected from the participants were solely used in this article and not shared with any third party.

4. Results and analysis

4.1 Critique and design revisions of the AR prototype

Participants in two groups answered six open-ended questions to share their opinions and experience of the AR prototype and the gamification component. The second group evaluated the AR prototype, while the third group evaluated the AR prototype with the gamification quiz. The questions examined how the AR prototype and the gamification quiz could get participants to get more motivated in their learning processes, what they expected to gain from using the AR prototype and the gamification quiz, what would keep them from using it, what difficulties they experienced, and what they liked as well as disliked with the design. In the following, participants will be presented as P1, P2, and so forth to maintain anonymity.

The primary challenge that emerged was that the AR prototype did not function properly. For some participants, the boxes disappeared at regular intervals or were shaking. One participant provided the feedback: "*The prototype itself was working, but on iOS, the boxes were wiggling around on the screen and were distracting*" (P1). Another also described issues with the 3D models, but with the addition that "*It was fun to play around and get a visual. However, it was at times difficult to keep all boxes visible*" (P2). The feedback implies that an AR prototype that does not function consistently may result in lower user satisfaction and the perception that AR may not have satisfactory educational value. The potential implications could lead to participants refraining from using it in their studies. The following revision was proposed based on this feedback:

> **Design revision 1:** This issue is related to the pattern ratio in the AR Marker Training tool, which was set to 50% to stabilize potential shaking of the boxes. However, since some participants still experienced shaking, there is a need to decrease the border's thickness that triggers the 3D models to stabilize the shaking. The shaking is also connected to natural light conditions, the quality of a smartphone camera, and the software used to identify AR objects.

Another issue that emerged concerning the prototypes' augmented reality function was that some participants considered the markers and the color range sliders to be small. The size made it difficult to see the colors, and one participant emphasized the following: "*The markers were quite small, which made it hard to see the different colors*" (P3). It was also difficult to change the color range sliders while retaining the augmented reality function. It was suggested that the prototype should display the percentage values for H, S, and L to support the comprehension of how the HSL color system works, as pointed out by one of the participants: "*It would have been more clear with the percentage value in the figure for HSL as well*" (P4). This feedback puts forward the importance of clarity and discoverability of design elements that are essential for the interaction with the AR prototype. The potential implication of inaccessible design elements may lead to less interaction and motivation when using the AR prototype. The following revision was proposed based on this feedback:

> **Design revision 2:** The size of the 3D models was increased, and the color range sliders were relocated to the bottom of the screen to maintain a display area of the AR simulation while modifying the color range sliders. The design of the color range sliders was also updated to show specific color values instantaneously when

> changing the color range sliders. These changes could assist users in gaining a better understanding of how the relationship between the degrees on the color wheel and the percentage values works.

Further, some participants emphasized that additional content could be needed to clarify the prototype's purpose and area of use. One participant concluded that: "*It is unclear what information is relevant to absorb, how I use what I can see in the prototype in my work, for example. Maybe it could have been included in the prototype instead of having a separate document with information about HSL.*" (P5). Another had a similar opinion: "*It might be too difficult to understand everything and especially the purpose of the prototype*" (P6). A few participants in group two suggested adding gamification would make the prototype more functional and add more value. For example, one participant had the following reflection: "*One thing could be to try to match a specific color of an object, for example. Maybe create a game where you can get points for every right color.*" (P7). This feedback indicates the importance of context because it could support participants to connect and create a meaningful, credible, and authentic relationship with the AR prototype and the subject of study. The following revision was proposed based on this feedback:

> **Design revision 3:** Several students in both groups emphasized a lack of purpose for the prototype and the area of use for HSL. Therefore, an implementation of clarification of how HSL is used in web development was added into the interface. In the "Color" box, where the result of the HSL values is shown, a code example in relation to the given values was added to contribute to more context and knowledge of its actual use in web development.

The third group provided additional criticism and requested further information to be included before the quiz. Some participants expressed confusion about what to focus on while testing the AR prototype. One participant indicated the following: "*I did not know that I was supposed to learn something from the AR model. So, I did not expect to gain anything. If I had a little more information on why I was using it, I probably would have tried to play around with it more to figure out how the HSL system works*." (P8) In addition, several participants mentioned that adding an exit button to the prototype would improve user-friendliness and make the gamification quiz easier to complete. One participant made the following observation: "*Maybe it would have been more rewarding for learning to go back to the prototype when you know what kind of questions you get. Then it becomes more like practicing and rehearsing.*" (P9). This feedback demonstrates the significance of designing a prototype that clarifies what is expected of the participant and makes it simple for a participant to find essential information (e.g., instructions on what to explore and pay attention to) while interacting with the prototype. The following revision was proposed based on this feedback:

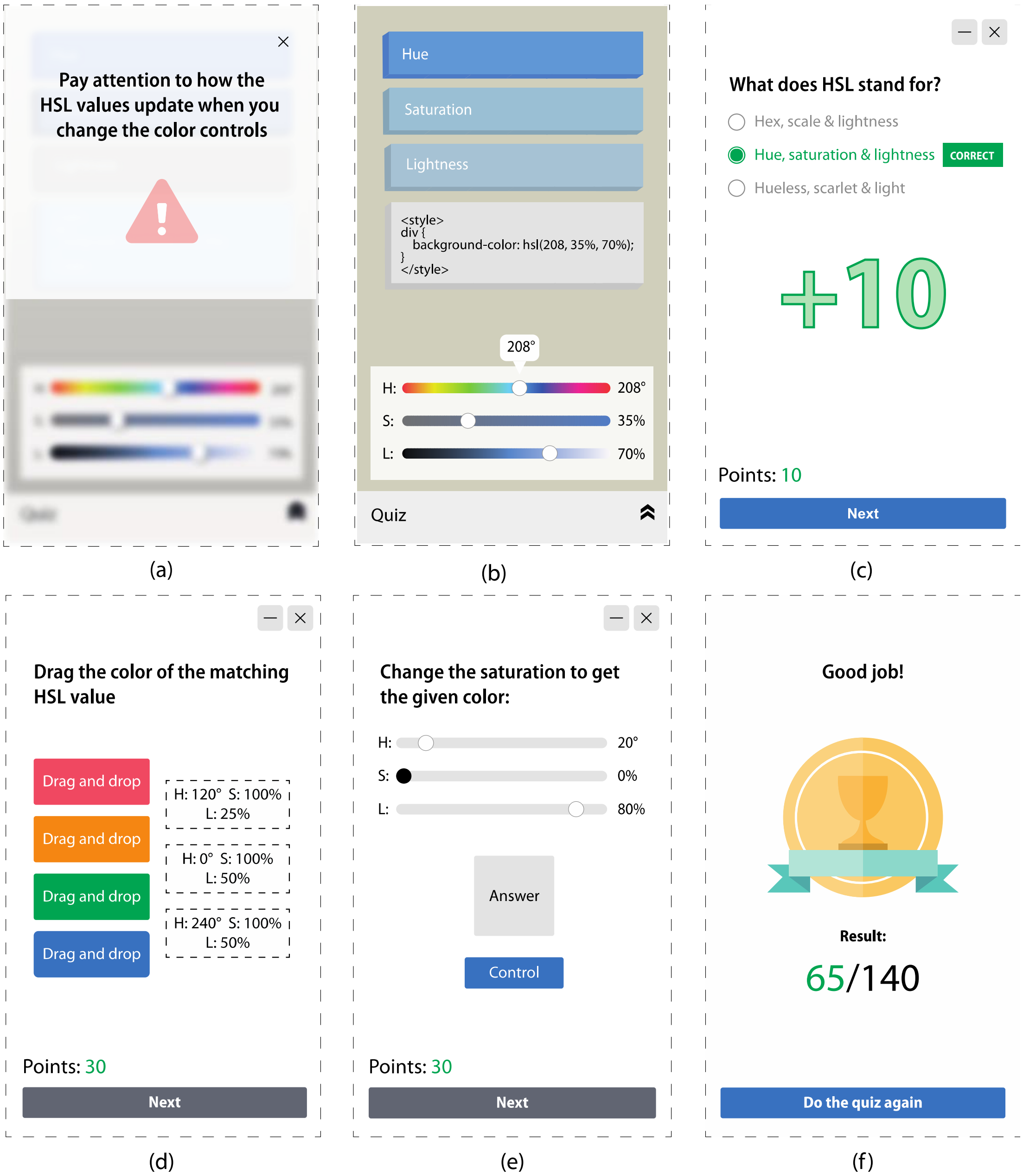
> **Design revision 4***:* An information pop-up screen was added to emphasize that the participants should focus on the HSL values when experimenting with the AR prototype. Also, an up-and-down button was added to the interface, allowing users to exit the gamification quiz and return to the HSL range sliders before answering the questions in the quiz. Participants' uncertainty about what they need to learn before the quiz could be supported by exiting, practicing, and returning to the quiz.

The final critique concerned the nature and complexity of the quiz questions because several participants considered them challenging. One participant provided the feedback: "*I think it was a bit difficult to remember how the different components (HSL etc.) worked, so I was struggling to answer the questions where I was supposed to match the colors in the quiz.*" (P10). Most critiques about the gamification quiz focused on the color matching questions, and several participants reported that they answered those questions wrong. Another participant implied: "*I did not learn anything about the hue before the quiz, so those questions about knowing the right color were difficult.*" (P11). The critique denotes that a gamified quiz should be designed to exclusively boost participants' motivation to explore the content and deepen the learning process instead of evaluating their comprehension of the presented content. The following revision was proposed based on this feedback:

> **Design revision 5:** The design of the questions was updated because participants in the third group who evaluated the gamification quiz experienced difficulties with them. Instead of matching the right color with every HSL-value, each question focused on one value at a time to focus the attention of each value. A further design revision included a progression of difficulty for each answered question to challenge participants while taking their own learning pace into account. For the 3D models, each name of HSL, i.e., hue, saturation, and lightness, will be printed in full instead for clarification purposes.

Based on the mentioned five design revisions, the initial design concept was revisited and furthered to reflect participants' feedback on the AR prototype and the gamification quiz, see Figure 3.

Figure 3. *A revised design concept of the AR prototype and the gamification quiz based on participants' critique.*



The first screen (a) displays information text in the form of a pop-up which informs students to pay attention to the value of each color control. The second (b) presents the new design for the 3D models, which are bigger and also with full names instead of "H", "S" and "L", the relocated color controls and the additional percentage icon. The third (c), fourth (d), and fifth (e) display the questions, where specifically the fifth (e) is improved, along with new minimize and close icons. The sixth (f) shows the final step of the quiz where a badge and the total points are presented.

4.2 Contextualization of design concept

The design concept and the AR prototype were received well by participants. By and large, participants reported that it was enjoyable and engaging to interact with instead of solely reading lecture notes. The design concept was perceived as novel compared to traditional methods for content delivery (e.g., video, PowerPoints). By implementing 3D models using AR technology and a gamification quiz, students in higher education were provided an opportunity to explore new ways to interact with theoretical content to get more involved with their learning process.

Following the recommendations by Stolterman and Wiberg (2010), the design concept was compared with previous research to demonstrate its uniqueness. For example, one study examined how AR har could be integrated into course materials to support students in developing their skills in the context of fashion education (Elfeky & Elbyaly, 2021). However, their concept only provided students with additional theory in the form of video and audio, which do not allow for interaction. Another study investigated how AR technology could be used to assist students in developing a deeper understanding of biology through the use of 3D models as visual representations (Reeves et al., 2021). Their concept provided students with visual representations in the form of 3D models, but students could not modify or interact with the digital artifact. Allowing interaction can transform students from passive to active learners and contribute to increased engagement (Wang et al., 2018).

Other research proposed a design concept that investigated the possibility of incorporating AR and gamification into environmental education in Chinese universities (Mei & Yang, 2019). By implementing gamification, students could use a geolocation-based game to navigate to pre-determined destinations by following in-app clues. In addition, students received interactive and informative digital content about the campus environment via augmented reality (Mei & Yang, 2019). Their concept resembles this as both explore how augmented reality and gamification can be used to enhance learning in higher education. However, while previous research has combined augmented reality and gamification to support interaction in environments where one interacts with nature, the contribution made with this concept demonstrates how it can be done with educational materials such as course literature.

Ahmad et al. (2020) researched how gamification could enhance students' motivation in computer science and the results showed that gamification could be an effective tool in teaching and learning. In addition, Sailer and Sailer (2021) argued that gamified quizzes have a positive effect on intrinsic motivation in the context of learning. However, the design needs to focus on concrete and achievable tasks to motivate students and sustain their satisfaction during the learning process (Deif, 2017).

In this concept, the quiz focused on letting students evaluate their knowledge and allow them to experiment with different types of questions. In contrast to previous research, this gamification concept used points (i.e., a score distributed after every correct answer), badges (i.e., a medal received after finishing the quiz), and rewards (i.e., immediate feedback in the form of a positive audio tone for each correct answer). In other studies where gamification tools demonstrated successful results, additional game elements were implemented into the design. For example, Ahmad et al. (2020) included levels, ranks, and leaderboards, and Sailer and Sailer (2021) integrated leaderboards and team competitions. The exclusion of these game elements in this design concept may have affected the results.

The uniqueness of the concept is the combination of two digital technologies, i.e., AR and gamification, that builds on existing state-of-art research that has demonstrated positive outcomes in terms of motivation and learning experiences (Ferriz-Valero et al., 2020; Lee, 2012; Santos-Villalba et al., 2020; Vallera, 2019; Walker et al., 2017). In the next section, the results of the quantitative surveys and the learning analytics will be presented.

4.3 Evaluation of AR and gamification on motivation and learning

The quantitative online surveys in this article were used to examine the differences between three types of educational materials in this study: (1) lecture notes; (2) augmented reality and; (3) augmented reality with gamification. In the following, the results from the data analyses will be presented. As recommended by Greenland et al. (2016) and Wasserstein et al. (2019), a surprisal value (s) will be provided where applicable. The dependent variable was motivation scores and the independent variable was educational materials.

A one-way analysis of variance (ANOVA) indicated differences in motivation between the first, on the one hand, and second and third groups, on the other. There was homogeneity of variances, as assessed by Levene's test for equality of variances (p = .06). More specifically, participants who used augmented reality (M = 3.69; SD = .56) or augmented reality with gamification (M = 3.67; SD = .51) reported higher motivation than those who only read lecture notes (M = 3.31; SD = .37), $F(2, 92)$ = 6.721, $p < .005$, s = 8.97, $\eta_p^2 = .13$. The value .13 for partial eta squared is considered a small size effect according to (Cohen, 1988).

Tukey post hoc analysis revealed that the difference in motivation between the first and second group (.38, 95% CI [0.10, 0.67]) was statistically significant (p = .005, s = 7.64). The difference in motivation between the first and third groups (.37, 95% CI [0.08, 0.65]) was also statistically significant (p = .008, s = 6.97), but no other group differences were statistically significant. Additional analyses of motivation scores showed no differences by age or gender. The results suggest that using augmented reality in higher education increases motivation compared to conventional learning materials such as lecture notes but does not seem to be enhanced by the adoption of gamification.

Furthermore, the learning analytics provided insights into participants' comprehension of the lecture notes when using augmented reality with gamification. The following data were saved in a database: participant's responses to the different questions, accuracy, and total score of the gamification quiz. The gamification quiz consisted of 11 questions divided into three categories: (1) five multiple-choice questions; (2) three questions matching HSL values with colors and; (3) three questions estimating HSL values based on given colors. The total accuracy for the first category was 80%, for the second 44.5%, and the third 30%. The gamification quiz had a maximum score of 140 points because specific questions generated more points than others. An analysis of the total score showed that the overall accuracy of the gamification quiz was 58% (M = 81.15; SD = 35.61). These results indicate that questions designed to require further cognitive resources may impact the accuracy of the gamification quiz. Another potential explanation could be that participants did not spend enough time on the AR prototype to comprehend the theoretical content. They also could not go back to the AR prototype for rehearsal purposes once the quiz started, which may have led to answers being based on educated guesses rather than comprehension.

5. Discussion

This article aimed to examine how AR and gamification could be combined to enhance students' intrinsic motivation and learning with physical course literature about web development in higher education. The concept-driven design research approach by Stolterman and Wiberg (2010) was used to conceptualize, design, and evaluate an AR prototype with a gamification quiz. The quiz introduced students to the HSL color system using three types of questions: multiple-choice, matching, and estimation of HSL values. It included gamification elements such as points, badge, progress bar, visual and audio feedback.

Previous research concerning AR has demonstrated the potential to enhance individuals' engagement, motivation, and learning experiences in educational tasks

(Chang, Hu, et al., 2019; Reeves et al., 2021). The results of the web-based experiment corroborate past studies and suggest that using AR could increase students' motivation compared to conventional methods such as reading lecture notes. Students' motivation may have enhanced due to their interactions between the physical instructional content and the virtual objects in the AR learning environment. Creating virtual spaces that enable intuitive interactions, feelings of immersion, and a sense of physical presence have shown to be essential factors for motivating learning (Hsiao & Rashvand, 2011). Another explanation is that incorporating AR in physical learning environments could support students to develop their practical and creative thinking. By contributing with interactive technology, it is possible to increase students' motivation, curiosity, and willingness to explore various learning paths (Elfeky & Elbyaly, 2021).

Looking at the qualitative results, students felt that the AR prototype was imprecise in its purpose. More specifically, they considered that the AR prototype lacked sufficient clarity and information about what to do before the quiz. This feedback shows the importance of designing a prototype that clarifies what is expected of students. The design needs to avoid abstract and complex tasks and instead focus on concrete and achievable content to motivate students and increase their motivation during the learning process (Deif, 2017; Mitchell et al., 2020).

Furthermore, research of gamification has shown to have mixed effects on intrinsic motivation. While research has demonstrated that gamified quizzes could positively affect intrinsic motivation in learning contexts (Sailer & Sailer, 2021), other studies have found no effect (Mekler et al., 2017; Mitchell et al., 2020). This study confirms earlier research and shows that the combination of AR and gamification did not affect students' motivation or learning. The results could be explained by the design and types of questions that may not have provided optimal challenges and corresponded to students' prior knowledge and skills (Zainuddin et al., 2020). The learning analytics, which provided insights into the participants' comprehension of lecture notes when using augmented reality with gamification, showed that the overall accuracy of the quiz was 58%. A breakdown reveals a notable difference between the first type of questions (multiple-choice), on the one hand, and the second and third types (matching and estimating HSL values), on the other hand. For the first category, the accuracy was 80%, for the second 44.5%, and for the third 30%. The matching and estimation questions seem to have failed in providing optimal challenges and may have affected students' motivation and learning.

The qualitative data indicate that the gamification quiz was perceived as a fun and innovative way to learn since several participants suggested it was enjoyable and inventive. However, they also felt that some of the questions were difficult, which may have affected their motivation. It has been suggested that there needs to be a balance between satisfaction achieved through success and learning gained through failure in gamification design (Deif, 2017). In other words, failure may contribute to learning, but if it becomes excessive, it could harm encouragement in the learning process.

Regarding methodological considerations and limitations, the current research was faced with time constraints that led to a relatively short intervention with both limited measurement items and game design elements. Further, the experiment was not conducted in a classroom setting or embedded in a lecture, which could have influenced the results. Novelty effects of gamification cannot be ruled out in the current study, and there is a need for long-term gamification implementation to examine these potential effects (Bai et al., 2020). While the wording of the self-generated questions and answers in the gamification quiz might have influenced participants' responses, the qualitative data showed no such indication. In contrast, the major strengths of this study include a pseudo-randomized between-subjects design and high internal consistency reliability of the measurements.

AR can contribute with additional context and deeper understanding of theoretical content, which could make learning easier and more accessible for individual students. Future work may consider exploring different paths when designing gamified quizzes for higher education. Instead of adopting a linear approach, as in the current study, it may be more viable to let students choose, customize, and explore educational content based on their needs and preferences.

6. Conclusions

This article theoretically underpins, elaborates, and evaluates a design concept that aims to enhance students' intrinsic motivation and learning when using AR and gamification with physical course literature about web development in higher education. The concept represents a potential of implementing digital technology with conventional education materials to broaden students' possibilities in their learning processes. From a theoretical perspective, the concept provides insights into how AR with or without gamification impacts intrinsic motivation and learning using a distinct combination of game design elements (points, badge, progress bar, visual and audio feedback) with a particular part of a subject (the HSL color system in web development) in a specific context (higher education). AR could enhance intrinsic motivation, but the combination with gamification did not seem to impact intrinsic motivation or learning and requires further investigation. The results of this research could serve as a basis to further gamification in higher education and support authors in the design of AR in course literature.

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