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# Co-design of mini games for learning computational thinking in an online environment

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## Abstract
Understanding the principles of computational thinking (CT), e.g., problem abstraction, decomposition, and recursion, is vital for computer science (CS) students. Unfortunately, these concepts can be difficult for novice students to understand. One way students can develop CT skills is to involve them in the design of an application to teach CT. This study focuses on co-designing mini games to support teaching and learning CT principles and concepts in an online environment. Online co-design (OCD) of mini games enhances students' understanding of problem-solving through a rigorous process of designing contextual educational games to aid their own learning. Given the current COVID-19 pandemic, where face-to-face co-designing between researchers and stakeholders could be difficult, OCD is a suitable option. CS students in a Nigerian higher education institution were recruited to co-design mini games with researchers. Mixed research methods comprising qualitative and quantitative strategies were employed in this study. Findings show that the participants gained relevant knowledge, for example, how to (i) create game scenarios and game elements related to CT, (ii) connect contextual storyline to mini games, (iii) collaborate in a group to create contextual low-fidelity mini game prototypes, and (iv) peer review each other's mini game concepts. In addition, students were motivated toward designing educational mini games in their future studies. This study also demonstrates how to conduct OCD with students, presents lesson learned, and provides recommendations based on the authors' experience.

**Keywords** Online co-design · Computational thinking · Mini games · Virtual reality · Game-based learning · Smart learning environments · Nigeria

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## 1 Introduction

Computational thinking (CT) is foundational knowledge for computer science (CS) students in introductory programming classes. CT is a fundamental step toward building problem-solving skills that can aid the understanding of programming (Agbo et al., 2019a). Studies have shown that understanding the characteristics and common practices of CT, such as problem decomposition, abstraction, algorithmic thinking, and problem-solving skills (Grover & Pea, 2013), are essential for students to excel in programming classes (Eguchi, 2016; Korkmaz et al., 2017). Introductory programming can be difficult for novice CS students (Malik et al., 2019). In the context of a developing country, e.g., Nigeria, this problem persists and has caused increasing failure rates among students who enroll in programming classes (Oyelere et al., 2018; Sunday et al., 2020). A previous study (Agbo et al., 2019a) recognized the potential of exploring CT approaches in higher education institutions (HEI) to allow students to gain the problem-solving skills required for advanced programming classes. Demonstrating CT competencies can be achieved through educational games designed to teach students basic CT concepts (Ch'ng et al., 2019; Mathew et al., 2019; Toivonen et al., 2020). In addition, games and game-based learning (GBL) promote interaction, engagement, and motivation for continuous learning (Al-Azawi et al., 2016).

Educational mini games deployed within a virtual reality (VR) environment can create better learning achievement through complete immersion (Chaves et al., 2019; Bouali et al., 2019). VR mini games allow learners to interact with real-world problems modeled as short mini games to deliver simple and tangible learning objectives (Bouali et al., 2019). Mini games are small, simple games that may exist within a bigger video game that can be played independently (Devisch et al., 2017). Research on transforming the traditional education environment into an immersive VR environment is receiving increasing attention (Freina & Ott, 2015; Virvou & Katsionis, 2008). A VR based mini game is an effective way to ensure that the learner is completely immersed, has a sense of presence, and interacts with objects in a learning environment to gain a better outcome and learning experience (Hickman & Akdere, 2018). In addition, VR has been widely used to support training and instructing students and professionals in different disciplines (Chittaro & Buttussi, 2015; Dias et al., 2019; Lindblom et al., 2021; Tobar-Muñoz et al., 2016). Therefore, a desirable approach to present CT concepts in HEI is to leverage VR technology and GBL (Chaves et al., 2019).

This study is a step toward designing a VR game-based smart learning environment (SLE) to support the understanding of CT. A learning environment is considered smart when it provides a high level of immersion, interactivity, personalization, and engagement to adapt to learners' needs and provide intelligent feedback based on learners' characteristics and learning progress (Agbo et al., 2019b, c, 2020a). Specifically, the current study attempts to demonstrate how co-designing in an online environment helps students design their own learning and develop CT skills. Some of the outputs from this study will form part of the mini games to be developed into a VR game based SLE to support students' further understanding of CT by giving them full immersion, rich interaction, personalized learning experience, presence, and engagement. In other words, the resulting artefact would promote learning and give the students a tangible learning object. A similar study that provides a VR environment to teach and learn CT concepts exists (Parmar et al., 2016); however, the approach used by Parmar et al., (2016) to design their VR game, i.e., Virtual Environment Interactions, which they refer to as VEnvI, to teach CT was not co-designed with CS students, which means it is not completely student-centered. Therefore, our study takes a different approach wherein mini games for learning CT were co-designed with CS students in an online setting. Therefore, the resulting output from this study could be refined into a student-centered solution to learn CT.

Learning elementary programming and CT through indigenous games and puzzles is not new in Nigeria (Oyelere, 2018). However, the design and implementation of indigenous games that engage students to innovatively co-design contextual mini games to support their understanding of CT and programming concepts remain insufficient. This study contributes to knowledge growth by designing and implementing an online co-design (OCD) process with CS students in a Nigerian HEI with the goal of supporting their understanding of CT principles. Specifically, this study aims to engage students in co-designing mini games that would improve their competency in problem abstraction, decomposition, algorithmic thinking, and recursive thinking though OCD. In this study, we refer to OCD as a process that involves researchers and participants in co-designing artifacts remotely by leveraging online platforms. A similar study that recently explored the use of an online environment to co-design a CS curriculum for teachers' professional development exists (Grover et al., 2020). As reported by Grover et al. (2020), teachers and researchers from four US States were recruited to participate in the study. Differing from that study, our study focuses on co-designing educational mini games with CS students to support their own learning through the OCD process. It has been reported that the OCD process itself creates opportunities for students to learn CT through collaborative co-designing activities (da Costa et al., 2017). Specifically, this study contributes to existing knowledge by showing how to co-design educational mini games in an online environment. The authors anticipate that co-designing in an online environment will become a future paradigm for conducting user-centered research, particularly if global challenges, such as the Coronavirus pandemic, persist. To the authors' best knowledge, a study to investigate the OCD process to create digital mini games in the context of Nigeria has not been conducted before. In addition, this study reports lessons learned from the OCD process and, based on the experience gained, provides recommendations that may be useful to educational game researchers. To achieve our objectives, we will provide answers to two research questions:

RQ1. How does OCD of contextual mini games with students in a Nigerian HEI work from the researchers' perspective?

RQ2. What are the experiences of students participating in an OCD of mini games to support their CT skills?

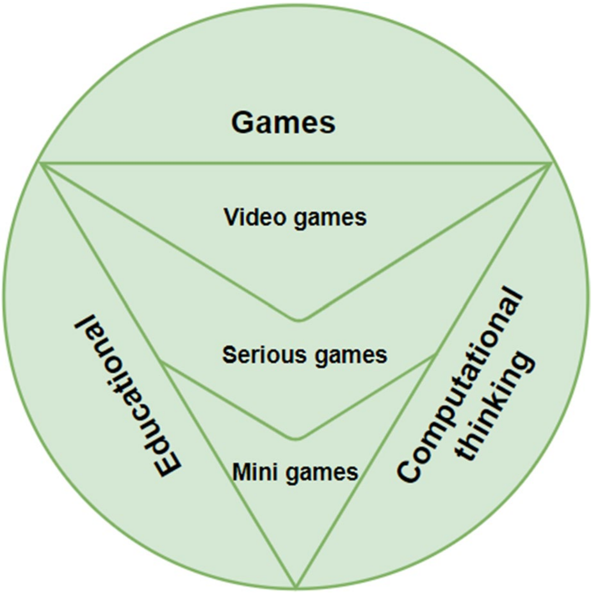
## 2 Background and theoretical framework

This section explains the major concepts and presents the contextual background of this study. In addition, we present an overview of relevant theories that support the design and development of SLEs for VR mini games to teach and learn CT and programming concepts.

### 2.1 Mini games and VR

Mini games have attracted increasing attention as educational tools that have the potential to teach difficult concepts to students (Asal et al., 2018). What is a mini game? We define educational mini games as short types of video games that are built within an educational application and that are independent in terms of game elements and mechanics, thus making them playable on their own (Fig. 1). Unlike serious games (Chittaro & Buttussi, 2015), mini games are flexible, simple, and easy to learn. These characteristics make it possible to achieve a small unit of learning, i.e., a mini game, similar to microlearning (Devisch et al., 2017). Moreover, learning in small chunks can provide a high level of interaction and aid learners' memory (Bruck et al., 2012). Designing mini games to support learning CT concepts can positively motivate students (Ch'ng et al., 2019) by structuring learning into smaller units (mini games) so that students can quickly grasp CT knowledge (Bakker, 2014). For example, to complement online learning, Arnab et al. (2020) conducted a study

**Fig. 1** Operational definition of educational mini games



on designing mini games to support microlearning within an open educational resource context. That study found mini games to be a modular approach in terms of portability and flexibility, highly interactive, engaging, and connects learning objectives. Therefore, this study is motivated by these findings to create mini games to support understanding of CT concepts.

Currently, mini games deployed in VR environments are receiving considerable research attention (Parong & Mayer, 2020). Studies show that mini games played in VR environments present tremendous opportunities for adequate immersion, motivation, engagement, and interaction to enhance learners' learning experience (Chaves et al., 2019; Bouali et al., 2019). VR technology is not new, however, recently, its deployment and use in the field of education and training has increased dramatically (Zhou et al., 2018). Current technologies have made it possible to deploy VR applications on small devices, such as smartphones; thus, VR applications are accessible to many users, especially in developing countries. For instance, in Nigeria, the use of VR technology to support learning is possible since most students possess smartphones capable of deploying such learning applications (Agbo et al., 2019b, c). Another beneficial characteristic of VR technology in an educational context is the ability to intelligently detect and track head movement, hand gestures, and body movement using embedded sensors (Virvou & Katsionis, 2008). These features are useful in creating highly interactive educational mini games that engage learners for an enhanced learning experience. Furthermore, VR technology and devices are considerably more affordable than they were decades ago. For example, companies, such as Google and Facebook are currently producing affordable head-mounted displays (HMD). This affordability creates ample opportunities for the deployment of VR mini games in the context of developing countries, such as Nigeria, where university teachers and students can afford HMDs. Consequently, the authors are conducting research to support students to learn CT concepts through the OCD of mini games. In addition, the resulting artifacts that would emerge from the co-designing process, i.e., VR mini games, would provide enhanced CT learning experiences.

### 2.2 Learning theory: Constructivism, experiential, and participatory

According to scholars, GBL is generally connected to constructivism and experiential learning theories (Koivisto et al., 2017; Wu et al., 2012). It has been recognized that GBL provides effective learning outcomes in terms of immersion, motivation, and stimulation for continuous learning (Alamanda et al., 2019; Huizenga et al., 2019; Tokac et al., 2019). A recent study by Radianti et al. (2020) revealed that few studies on VR game-based educational applications connect the foundation for their research to any learning theories. Therefore, this section focuses on the fundamental learning theories that connect GBL, educational VR applications, and the co-design process. While this study does not dwell deeply on the learning theories, it connects the co-design process and GBL to the existing and relevant theories that support the aim of this study. The overall goal of connecting these relevant theories is to provide the foundation for designing a game-based VR interactive learning environment to support CT and programming education, which is the authors' long-term plan where the current study serves as input.

Generally, educational tools are expected to support teaching and learning processes in formal, nonformal, and informal settings (Pérez-Sanagustín et al., 2014). Currently, the use of games and GBL has become a strong approach for creating educational tools (Qian & Clark, 2016). In addition, GBL has been investigated to determine whether it can provide rich instructional content to learners in various disciplines, such as engineering and computing, health and medical science, art and design, languages, and mathematics (Chang & Hwang, 2019; Tokac et al., 2019). For example, previous studies have considered the use of games to gain more awareness and knowledge in sport and physical health education (Mubin et al., 2016; Regal et al., 2020), games to promote learning in the fields of arts, culture, and tourism (Cesário et al., 2019; Rinnert et al., 2019), and games focused on engineering and manufacturing education (Perini et al., 2018; Tobar-Muñoz et al., 2016).

The co-design process has become a popular method for designing a GBL tool to support students (Loos et al., 2019). The goal of the co-design process is to increase originality in the game in terms of meeting the requirements of the targeted players and to avoid biased assumptions arising from designers and developers of the game (Vetere, 2009). In addition, co-designing educational mini games with targeted stakeholders provides opportunities for designers and developers to uncover the differences in players' individual learning characteristics that can be modeled into the game to enhance personalization of the gameplay (Castro-Sánchez et al., 2019; Mariager et al., 2019; Thabrew et al., 2018).

Broadly, GBL and the co-design concept are grounded in three interwoven theories: constructivism theory (Jong et al., 2010), participatory design theory (Gomez et al., 2018), and experiential learning theory (Kolb, 2014). For example, participatory design theory is founded on constructivism theory (Spinuzzi, 2015). While constructivism theory postulates learning as an active, constructive process where learners create their own mental representation of learning objectives, participatory design theory deals with methodological approaches that ensure that users of technological artefacts are involved in the entire design process (co-design) of what affects them in order to create more efficient and usable systems (Bowen, 2010; Robertson & Simonsen, 2012; Rosenzweig, 2015). On the other hand, experiential learning theory views learning as a process whereby concepts are derived from and are continuously modified by experience, that is, "ideas are not fixed and immutable elements of thoughts but are formed and re-formed through experience" (Kolb, 2014, p. 26).

Figure 2 shows the relationship between these theories and how they are connected to provide the foundation for the design and development of VR game-based smart learning environments to teach CT and programming concepts.

These theories are relevant to this study because they provide the foundation for building a learner-friendly smart learning environment through the OCD process. According to Kommers (2003), combining experiential learning in a VR environment with constructivist concepts can provide a standard interface for an immersive learning experience that meets the expectation of future learning tools.

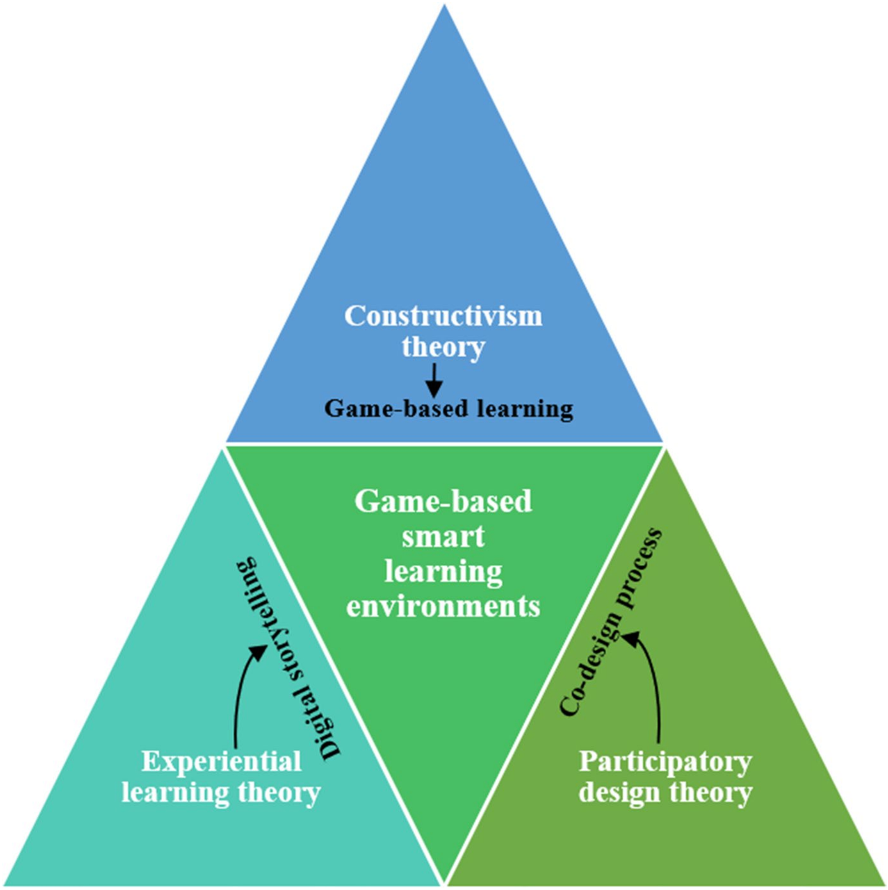



**Fig. 2** Interrelationship of relevant theories of game-based smart learning environments

### 2.3 OCD of educational games

Different methodologies and techniques can be applied to design digital games to support learning. For example, Walsh et al. (2010) described a technique called "layered elaboration" as a new approach to co-design with children. According to the authors, this technique is a useful way to co-design since an initial idea by a co-designer can be built upon by another designer without modifying the original items. Several activities are involved in co-designing a digital game with stakeholders, such as brainstorming exercises, card sorting, sticky note exercises, group tasks, diagramming, and rapid paper prototyping (Ruiz et al., 2018). In our study, a co-design technique motivated by Walsh et al. (2010) was used since it sufficiently fit the context of educational game design to support students who, in this case, are the primary users of an artifact that would emanate from this co-design process (Havukainen et al., 2020).

The traditional face-to-face method is often used to co-design educational or commercial product. In this method, the researcher/facilitator meets with co-designers for a participatory process that leads to the creation of a new artifact (Bonsignore et al., 2016; Hjelmfors et al., 2018). However, conducting a co-design process in an online environment is an innovative approach that could be explored by researchers. This method provides a flexible way for researchers, facilitators, and stakeholders to participate in a co-design process through an online medium. During the co-design process all communication between stakeholders could occur with the help of an online platform. This type of OCD process is useful, particularly in situations where stakeholders are faced with various difficulties, such as distant geographical locations, time differences, and other circumstances that make it impossible to have a face-to-face meeting, such as a pandemic.

A reasonable number of studies connected to OCD process can be found in the literature. Some of these studies focused on co-designing commercial products to improve customers' motivation and engagement to buy and use a product (Dix et al., 2012). A few studies focused on co-designing online courses to support pedagogy and educators' professional development (Grover et al., 2020; Marín et al., 2018). To investigate co-designing an educational tool, Walsh et al., (2012) conducted an OCD process with children to design a prototype for a computer-based design tool—DisCo. This tool was designed to facilitate collaborative work through drawing and annotation of objects among geographically distributed participants. Their study revealed some limitations, including the inability for the participants to draw conveniently on a computer screen (Walsh et al., 2012). In addition, Friedrich (Friedrich, 2013) conducted a study on how social media platforms can support the participation of stakeholders in an online co-designing process. The output of this study was the online collaboration tool called Open Web Lab, which provides social media elements to facilitate the co-design process (Friedrich, 2013).

The recent global pandemic, which has affected researchers from all fields, including education, has created the opportunity to develop innovative ways of co-designing artefacts with users in an online environment. Our idea of an OCD process entails a situation where the researchers and students implement the co-design remotely through online platforms. The students worked remotely within a closed online group to collaborate and create their mini game prototypes. However, students could choose to have a physical meeting without the researchers to implement their collaborative tasks because, when the study was conducted, physical meetings were still possible in the country where the students reside. This OCD process creates flexibility for students to effectively co-design with researchers. There are a few studies on co-designing educational tools in an online environment; however, to the best of our knowledge, no studies focus on co-designing educational mini games to support CT skills in an online environment, specifically in the context of Nigeria. Therefore, among other objectives, this study contributes to the body of knowledge in this regard.

### 2.4 Educational games and interventions for CT in the Nigerian context

This section presents an overview of concepts and interventions to support CT-related skills in Nigeria. To start with, the game approach, simulations, and multimedia tools to support CT skills in Nigeria have been investigated and found to be useful in terms of engaging and enhancing students' learning outcomes (Adetunji et al., 2013). Scholars are making efforts to promote teaching and learning through the design and implementation of games to complement the traditional approach of textual materials in Nigeria (Ogunsile & Ogundele, 2016; Oyelere, 2018; Bassey et al., 2020). For example, in the field of health and medicine, the use of educational games is gaining momentum. Fisher (2020) recently explored the potential of an educational game to facilitate civic learning in the context of Nigeria. Fisher's study examined how game approaches provide opportunities for civic engagement through participatory learning in a developing country. The author revealed that the use of games for civic education could facilitate community discussion and democratic deliberation through participatory learning. In addition, Bassey et al. (2020), designed a board game, Worm and Ladders, to promote education on good hygiene practices to control soil-transmitted helminthiasis (parasitic worm infection) in southwestern Nigeria. This study revealed the potential for teaching and promoting effective hygiene behavior among young people through the use of board games to complement other teaching methods (Bassey et al., 2020). Furthermore, a study on nutrition education among adolescents was conducted using an educational game to complement teaching and learning about how to practice healthy eating (Ogunsile & Ogundele, 2016). The findings from Ogunsile and Ogundele's study (2016) indicate that the use of the game for nutrition education is an effective approach to enhance adolescents' knowledge, attitudes, and healthy eating practices in southwestern Nigeria.

In the context of science, technology, engineering, and mathematics (STEM), a few studies were seen to set the foundations for the teaching and learning of CT in Nigeria. For example, recent studies have focused on developing the learning and teaching framework to build teacher's capacity to support CT education (Emembolu et al., 2019; Ramin et al., 2020). Through a concept of TeachAKid-2Code, Emembolu et al. (2019) recruited educators across nine Nigerian States to provide training and capacity building in order to increase the number of STEM educators in Nigeria. In another setting, Talib et al. (2019) conducted a study on enhancing students' critical thinking and CT skills using graphic calculator (GC) technology. This study showed that GC can be maximized as a pedagogical tool to benefit students' CT skills. Similarly, Adetunji et al. (2013) revealed that students from southern Nigeria who learned mathematics through a digital game performed better in problem-solving than those exposed to the traditional method.

In the context of HEI, not too many studies that addressed CT and programming education in Nigeria are available. However, it is worthy to note that some studies have been conducted to facilitate CT and basic programming education in the context. For example, Oyelereet al. (2018) designed and developed a mobile learning application to facilitate elementary programming by integrating Parsons programming puzzles into a traditional board game. Evaluation of the mobile learning application with Nigerian students reported that the tool promotes teaching and learning of programming by engaging the students in problem-solving through an indigenous game (Oyelere et al., 2019). It is also interesting to see how scholars from the university where the participants of this study emanate are making contributions toward developing students' CT and programming skills (Oladipo & Ibrahim, 2018). For instance, an intervention to support students on problem-solving and self-learning (CodeEazee) has been developed using Python (Oladipo & Ibrahim, 2018). In another study, Oladipo et al. (2017) developed a tool called FULangS using C language for the purpose of guiding the teaching of scripting through a command-line interface. All the studies presented from the HEI context have in some ways contributed toward developing CT skills among students in Nigeria. However, the focus has not been on the core concepts of CT, such as algorithmic thinking, problem decomposition, and recursive thinking. Therefore, there is a need for more research focusing on establishing teaching and learning of CT concepts in all levels of education including HEI. In this sense, the current study engages students to design contextual mini games through which they can gain CT knowledge and to develop the resulting mini games into a VR game based SLE to further support students in understanding programming concepts. As established earlier, an average Nigerian HEI student can afford a simple VR headset of about 5 US Dollars. In addition, teachers, and most of the students in Nigeria already possess smartphones that can support VR applications (Agbo et a., 2019c).

## 3 Methodology

This section explains the research procedures, participants, and description of the participatory student-centered design method (Bonsignore et al., 2016; Gomez et al., 2018) implemented through an OCD process and shows how a series of activities were carried out, which are explained in the subsections.

### 3.1 Participants and ethical consideration

This section provides information about the student participants, the research team, and the students' coordinator involved in the OCD process. The research team included a doctoral researcher, who is also the software developer, and a postdoctoral researcher, who is also one of the doctoral researcher's supervisors. Twelve CS students (eight males, four females) studying at a university located in the north-central region of Nigeria were recruited to participate in the study. Although the students were off campus during their participation, some were living in the city where the university is located. The study was planned to be completely online based. However, we discovered that some of the students had weak internet connections and would not be able to fully participate as a result. For students living close to the university who did not have a strong internet connection, the students' coordinator made a provision to allow them to use the university's CS lab. This alternative provision was made to allow the students in this category to participate in the first meeting that provided important information regarding how to participate in the study.

The students who participated in this OCD process were at different years/levels in their study. Four students were in their second year (200 level), four were in the third year (300 level), and four were final year students (400 level). The purpose of having students from various levels (years) of study to participate in the OCD process was to obtain an inclusive experience in terms of creativity and design perspective from all stakeholders. All the students who participated in the study had completed an introduction to computer science (CSC 101) course. Based on the targeted university's CS curriculum for year one, the participants should have been introduced to the basics of computer science, introduction to problem solving methods, and algorithm development. This prior knowledge was necessary to make each participant contribute meaningfully to the co-design activities. The student's specific data were obtained during a seminar while each person introduced themselves. Because the students are studying CS at the same university, they would probably be familiar with one another.

This study conforms to the ethical principles and guidelines of the Finnish national board on research integrity regarding responsible conduct of research (RCR). Prior to the seminar, the researchers obtained informed consent from each participant electronically. Some students were contacted to obtain their consent via phone calls. During the recruitment process, the aim of the study was explained to the students. It was mentioned in the consent messages that "the aim is to engage students in co-designing mini games that would improve their CT skills and provide state-of-the-art information regarding the use of recent technology such as VR in the educational field." The students were informed of their right to stop participating in the OCD process at any stage. The students' right to withdraw from participating in the OCD process was repeated during the seminar. Consequently, the rights and interests of the students were fully respected throughout the OCD process. Students also consented to allow the data collected during the OCD process, including their photos, drawn images, and text, to be used anonymously for research purposes.

### 3.2 Participatory student-centered co-design process in an online environment

To conduct this study, the researchers opted for OCD due to widely imposed pandemic-related travel restrictions. The travel restrictions made it impossible for the researchers and participants, who were located in different countries, to conduct a face-to-face co-design process. In such a situation, the OCD process became the necessary and available option (Grover et al., 2020; Walsh et al., 2012). In addition, it is worth mentioning that at the time this research

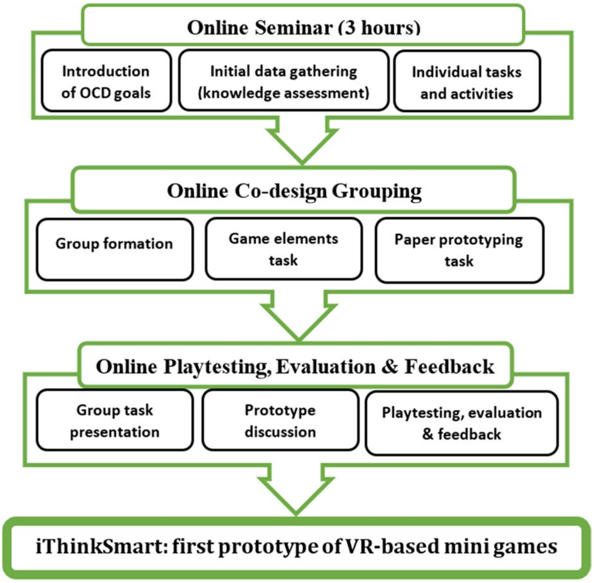



**Fig. 3** Screenshots showing the Zoom meeting between researchers and students participating in an online seminar (first session of the OCD process) where some students connected from different locations and others were gathered and connected from a university CS lab

was conducted only two Nigerian states, Lagos and Abuja, had reported Coronavirus cases, with a very low number of infections. Therefore, Nigerian authorities had not banned gatherings; Thus, people were allowed to carry on with their normal activities. Since the students could be reached remotely, the researchers primarily leveraged the Zoom[1] and WhatsApp[2] platforms to conduct the entire four-week OCD process. Research on the use of social media, such as WhatsApp, to facilitate learning has been conducted in the same context (Agbo et al., 2020b). Students participating in the OCD process required an internet connection and Zoom software installed on a computer or smartphone. Because some of the students could not access the internet from their locations, we arranged for them to use a university computer lab where a few students gathered to attend the first meeting. As shown in the screenshots in Fig. 3, the first meeting was held virtually.

During the first meeting, a three-hour seminar was held to provide an extensive introduction about the objectives of the co-design process, activities, tasks to be completed, and expected outcomes. Subsequently, the meeting continued at a group level with four students in each group created on the WhatsApp platform. The WhatsApp groups were created to facilitate collaborative work in the co-design activities. Group WhatsApp activities lasted for three weeks, and the meeting schedule and strategies in each group were defined independently based on what suited the members. However, to ensure effective collaboration among the group members on the assigned tasks, a researcher was assigned to each group to provide guidance and motivation to the participating students. Since the students could communicate outside the

1 https://zoom.us/
2 https://www.whatsapp.com/?lang=en

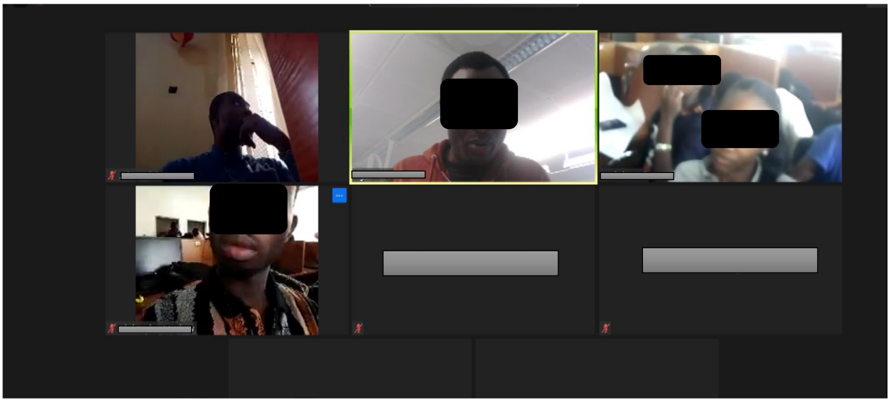


**Fig. 4** Implementation flow of the online co-design methodology

WhatsApp platform, other forms of collaboration among the students at the group level, including physical meetings, were possible. The researchers may be unaware of such meetings. After three weeks of group collaboration, each group submitted their completed tasks, which included all materials used in the conceptual design of the mini game, story and scenarios, puzzles, and problem-based challenges. The students were expected to connect their mini games and puzzles to at least one aspect of CT (problem-solving, abstraction, pattern recognition, and recursion).

The OCD process includes: (i) an online seminar (3 h) (ii) online co-design grouping, and (iii) online playtesting, evaluation, and feedback. The OCD methodology, as shown in Fig. 4, was implemented to reflect the interconnection of the relevant theories identified in Section 2.2 (Fig. 2). The first stage of the OCD process, a three-hour online seminar, introduced the objectives of OCD, emphasized the goal for co-designing, and described the types of activities that the students would undertake during the entire OCD process. For example, it was explained that the OCD goal was to conceptualize contextual mini games that teach basic CT concepts and that students would be able to understand CT through the conceptualization and design of mini games. These mini games would serve as input for the authors' long-term plan to develop a VR application containing mini games to support CT skills. Therefore, students were briefly introduced to VR technology and the concept of smart learning environments during the seminar.

During the seminar session, activities were recorded using Zoom's live recording option to allow the researchers to play back when necessary. In addition, during the first session, we took photos of the participants in the physical lab and screenshots of those online and connected through Zoom. The Zoom chat board was used to collect data from students who were online and paper-based exercises, such as sticky notes and flipcharts, were used to collect data from students in the university lab. As explained earlier, this approach of online activities creates a flexible way of co-designing where some students were connected to the virtual meeting from a physical location in a university lab and other students, including the researchers, were connected from different locations. The first activity in the seminar was self-introduction.

Afterwards, an initial assessment of the participants was conducted using an online survey form. The motivation behind the initial assessment was to understand the participants' background and prior knowledge in terms of discipline and level of experience of games and game elements. Furthermore, for students who were physically at the computer lab and could not use the online survey form, an individual sticky note exercise was used to elicit the same information gathered from the online survey.

The second stage of the OCD process was the online co-design grouping. We were guided by the students' year of study and their gender to form the group. For instance, group one consisted of students from year two to year four. The researchers ensured that there was one female in each of three groups. The researchers relied on the information already gathered from the students to select who should belong to what group. Details of the participants are provided in Section 3.1. In addition, the grouping was done such that every participant could meaningfully contribute (Gomez et al., 2018). A three-week agenda for the OCD activities was set by each group. A group leader was nominated by the group members. Activities within the group commenced immediately at the seminar and continued online for three weeks.

In addition, during the seminar, activities such as developing a game element wish list were completed on a group basis. Students discussed which game elements they would prefer to see in their conceptual mini games and made a wish list of such game elements. Then, students participated in a breakout session in groups to brainstorm on concrete problems they will identify to solve with mini games and how they want to solve those problems. The outcome from this brainstorming session was harmonized, written on a flipchart or the Zoom chat board, and presented upon returning to the main Zoom meeting room. The next group task was game ideation and prototyping. The researcher provided guidelines for the prototype exercise: (i) prototypes should consider two separate ideas of contextual mini games, (ii) the games should present CT problems which they intend to solve, (iii) the games should comply with the fundamentals of game elements (space, components, mechanics, goals, and rules) (E-lineMedia, 2011), and (iv) a contextual storyline for the conceived mini games should be created. The participants were encouraged to freely discuss all ideas and be creative in their design and prototyping (Jong et al., 2010). The context for their storyline could be anything that appeals to them from their experience (Kolb, 2014). For example, they could choose to create a storyline about the Nigerian context, such as ethnicities, government, politics, and the environment.

The final stage of the OCD process focused on online playtesting, evaluation, and feedback. Playtesting a co-designed mini game provides an opportunity for end users to evaluate their co-designed games (Eckardt & Robra-Bissantz, 2018; Gerling & Masuch, 2011). This stage required each group to submit their output and make a presentation. During the presentation, the groups discussed their ideas and evaluated each other. After the three weeks of collaborative group co-design, group leaders submitted all documents they had prepared during the task implementation, including paper prototypes, sketches, voice notes, videos, mock-ups, and PowerPoint presentations. All groups tried to model user-centered designs with digital prototyping using wireframes, e.g., using Corel Draw (Agboet al., 2019a, 2020b; Laine et al., 2020).

### 3.3 Data collection

In this study, the authors collected both quantitative and qualitative data (see Appendix). At the beginning of the seminar, the researchers administered a short online survey (Anyango & Suleman, 2018) where participants gave their responses regarding their prior knowledge and experience about co-design, games and game elements, and expectations from participating in the study. The survey instruments were administered on a five-point Likert scale (1 = strongly disagree; 5 = strongly agree). Items in the questionnaire were designed by the researchers based on the context of this study and were validated by three CS or educational technology experts prior to being administered (Anyango & Suleman, 2018).

Aside from the quantitative data collected during the seminar, the authors used different approaches to collect qualitative data. For example, qualitative data were obtained from sticky note exercises, Zoom chat content, and recordings collected during the seminar (da Costa et al., 2017). In addition, voice notes, paper designs, and prototypes were collected asynchronously during the group co-design activities (Spencer et al., 2019) (Fig. 5). In addition, at the end of the OCD process, a semi-structured interview was conducted with a single randomly selected student from each group. The reason for conducting an interview instead of administering a post-questionnaire survey was to gather more specific responses from the students

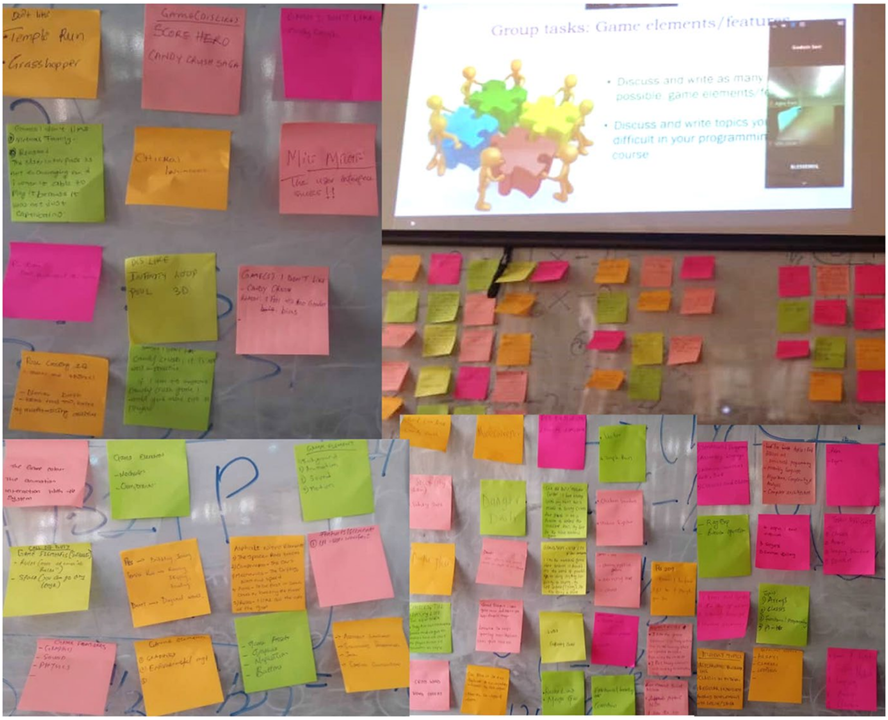



**Fig. 5** Portion of the sticky notes from a data gathering exercise

regarding their experience after participating in the OCD process. Besides, the sample size for the participants is small; thus, we considered that an interview would be more meaningful. The interviews were conducted through the Zoom platform.

The interviews were recorded and transcribed. The transcribed interviews were coded, and the guidelines provided by Moser & Korstjens (2018) were followed to present a content analysis of the coded transcript. In addition, the quantitative data were analyzed using descriptive statistics (mean and standard deviation). Analysis of the data collected from quantitative and qualitative method are presented in the findings section to complement our findings in terms of validity and reliability from the mixed-method approach (Natow, 2020).

## 4 Findings

The early part of this section presents the results that are focused on addressing the first research question. Specifically, we show the findings from the implementation of the student-centered OCD process including the analysis of seminar exercises, designs, and other data collected during the process. The remaining part of the section presents the results that address the second research question, i.e., participants' experiences after undertaking the OCD process of co-designing mini games.

To answer the research question (RQ1) *"How does OCD of contextual mini games with students in a Nigerian HEI work from the researchers' perspective?"* we begin by presenting the background information of the participants' in Section 4.1 and proceed to analyze the data collected during the OCD process. The analysis of the participants prior experience is necessary for the study as it helps to find out their post OCD experience.

### 4.1 Descriptive analysis of participants experience prior to participating in the OCD process

This study revealed several information items regarding the participants' prior knowledge and experiences in terms of the co-design process, games, and game elements. As shown in Table 1, the majority ($\mu = 3.82$, $\sigma = 1.17$) of the participants indicated that they had participated in an online seminar. Surprisingly, a slight majority of the students ($\mu = 3.64$, $\sigma = 1.12$) indicated that they had participated in an OCD process. Since this response was given before the actual seminar, students may have misunderstood the question as to what exactly an OCD process means.

As shown in Table 2, a majority of the students are active game players, primarily for fun ($\mu = 3.91$, $\sigma = 0.83$). However, a slightly smaller number of students ($\mu = 3.73$,

**Table 1** Prior participation in seminars

| Items | μ | σ |
|---|---|---|
| I have participated in an online seminar | 3.82 | 1.17 |
| I have participated in an online co-design process | 3.64 | 1.12 |

**Table 2** Prior knowledge of and experience with games and game design

| Items | μ | σ |
|---|---|---|
| I am an active player of games | 3.82 | 0.75 |
| I play games to gain more fun | 3.91 | 0.83 |
| I play games to gain new knowledge or learn new things | 3.73 | 0.79 |
| I have frequently participated in game design | 3.55 | 1.03 |
| I am familiar with the elements of games | 3.64 | 0.81 |
| I am aware of how game elements operate | 3.55 | 0.69 |

$\sigma=0.79$) play games to acquire new knowledge. A handful of students ($\mu=3.55$, $\sigma=1.03$) indicated that they had participated in a game design process; however, we observed that the data points of respondents are spread out over a wider range of values. A slight majority of students ($\mu=3.64$, $\sigma=0.81$) claimed to be familiar with game elements.

In addition, the study investigated the students' expectations regarding what they aimed to gain from participating in the OCD process. The results revealed that participants who attended the OCD seminar had high expectations. For example, the data presented in Table 3 indicates that most of the participants ($\mu=4.36$, $\sigma=0.81$) were eager to participate in the OCD seminar because they understood and welcomed the purpose of the seminar.

While most items indicating students' expectations in Table 3 show high scores, the question of whether the seminar will help the students identify a new CS area got a low score ($\mu=2.45$, $\sigma=1.57$). This result revealed that since students were already familiar with the seminar's purpose, as indicated in the invitation notice, they may not be expecting something new. Besides, all participants had passed an introductory programming course; thus, the topic would not be new to them.

In addition, the study analyzed the participants' responses regarding their personal experiences in understanding programming topics, i.e., what topics they found easy or difficult in their programming classes. The reason is to concretize the need for the current study by ensuring that student-centered game prototype is being designed and to provide useful information for future study. Although the sticky note exercise that was conducted during the seminar revealed certain information in this regard (Fig. 5), the analysis shown in Fig. 6 provides a clearer picture of the programming topics that the CS students found difficult to understand. The results shows that 55% of the students ranked "*recursions*" as very difficult to understand while 45% indicated that "*file and exception handling*" and "*methods*" were very difficult programming topics.

**Table 3** Participants' expectations of the OCD process

| Items | μ | σ |
|---|---|---|
| I am eager in participating in the seminar because the purpose in the invitation notice was clear | 4.36 | 0.81 |
| I am eager in participating in the co-design process because I like to collaborate and share knowledge | 4.18 | 0.87 |
| I expect to learn new things in the co-design seminar | 4.45 | 0.93 |
| I am hoping that the co-design seminar will help me identify new areas of computer science | 2.45 | 1.57 |
| The seminar will provide me the opportunity to design my own game | 4.45 | 0.93 |

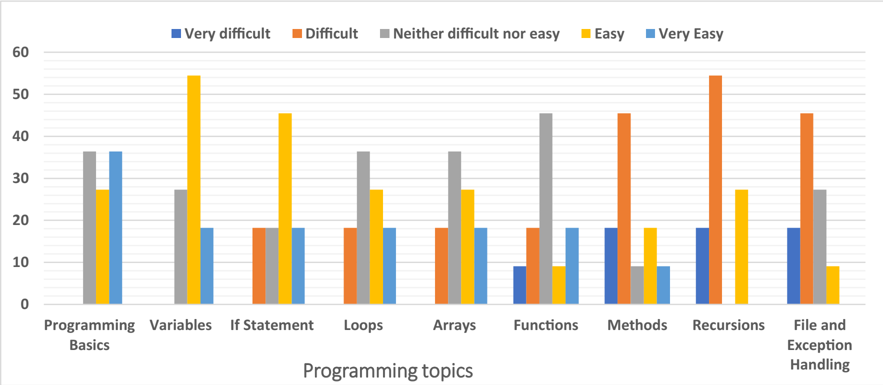



**Fig. 6** Participants' experience, ease/difficulty in understanding programming topics

### 4.2 Researchers' analysis of conceptual and contextual mini games co-designed by HEI students in Nigeria

This section presents the analysis of conceptual and contextual mini games co-designed by CS students in Nigeria following participatory design theory (Gomez et al., 2018). The analysis is based on researchers' perspective about concepts, activities, and student-centered approach followed by participants in the OCD process to create contextual mini games in an online environment. Here, the focus is on brainstorming with students on game features, game elements, and paper prototyping.

#### 4.2.1 Activities during the seminar: Sticky notes, selection of game elements, and game prototyping (paper and mock-up)

The sticky notes activity was designed to motivate students to begin to prepare their minds and refresh their memories about experiences they have obtained from playing any kind of game. Related to our discussion of various types of learning theory (Section 2.2), these experiences provide opportunities for students to actively contribute in terms of what functions they really wish to have in their mini games. The desires of each participants expressed in the resulting wish list indicate that they have a certain level of game experiences, as shown in Table 4.

Furthermore, in their groups, the students independently designed some conceptual mini games and puzzles using a paper prototype and later a wireframe. One of the researchers was added to each WhatsApp group to monitor the progress of the students' co-design. Figure 7 lists game elements and paper prototypes of mini games from the group OCD activities.

In addition, the researchers provided information on how each group could present their idea in digital form, e.g., by using a wireframe. Some of the groups were able to use software, such as Corel Draw, to transform their paper prototype into a mock-up design, as shown in Fig. 8a and b.

**Table 4** Classification of co-designers wish list of game elements

| Game elements | Wish list classification |
|---|---|
| Player | auto playing, character, avatar, |
| Environment | user interface, interaction, experience, accessibility, easy to play, user friendly, interactive space |
| Input/output | navigation, buttons, clear instructions, movements, gesture detection |
| Rule & Challenge | competitive, high challenge, constraints |
| Rewards & badges | scores, rewards, win, goals, winning sounds, leagues, cups, |
| Social element | collaboration, teamwork |
| Aesthetics | graphics, animation, colors, background, sounds, themes |

Worthy of note is the contextualization of ideas of game scenario, storylines, and game puzzles for teaching and learning of CT concepts (Malik et al., 2019) by the students who created themes around the context. For example, one of the mini games was named *Mount Patti treasure hunt* (Fig. 8a).

The storyline for this game was connected to a popular mountain located in the same city where the students reside. *Mount Patti* is 1503 feet tall above sea level and had long served as a tourist center in the locality. *Patti* is a native word meaning "hill." This mountain has many historical relics, such as the government house of Nigeria's first capital city. The co-designers created their storyline around this history and gamified climbing the mountain. The simple rule for exploring the mountain is to keep dodging falling rocks by correctly answering

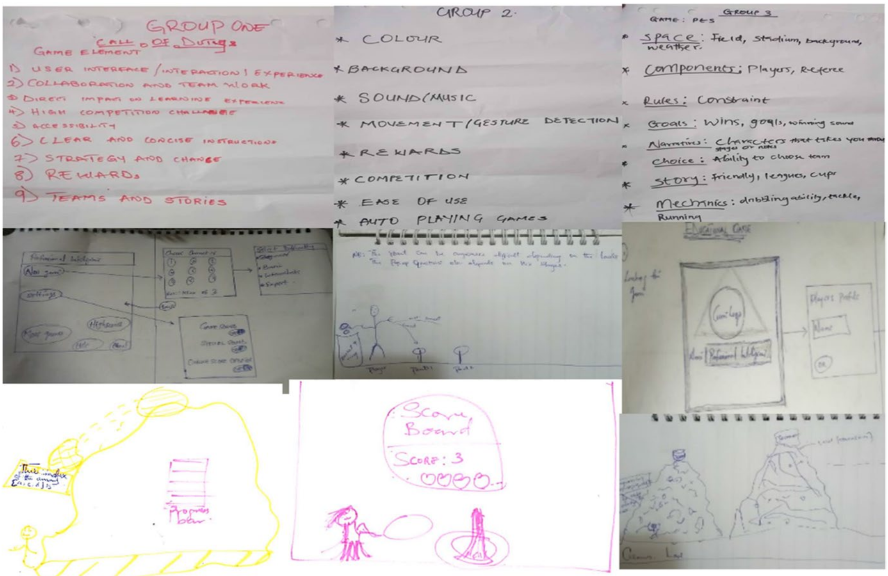



**Fig. 7** Outputs from group tasks on selection of game elements and paper prototypes

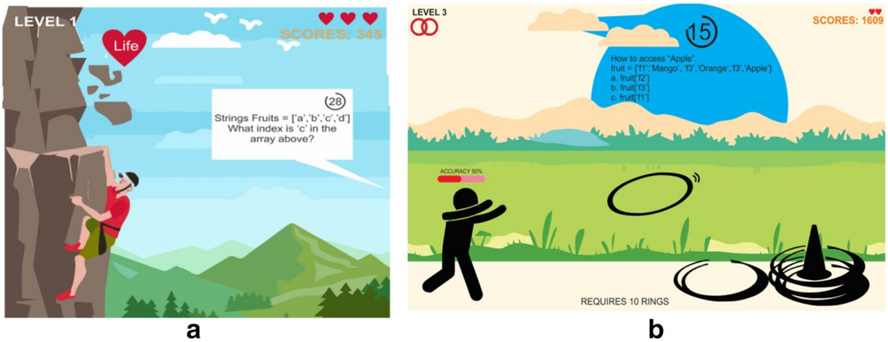



**Fig. 8** Screenshots of mock-up prototype of co-designed mini games. A. the "*Mount Patti Treasure Hunt"* mini game; B. the "*Targeted Throws"* mini game

some CT puzzles. If players answer a puzzle incorrectly, they will be crushed by the falling rock and pushed down a step.

Another example of a contextual mini game conceived by the students is the "Targeted Throws" (Fig. 8b). The idea behind this mini game connects to the usual practice in the context where youth compete in harvesting fruit by throwing objects at ripe fruit, such as mangos, oranges, and apples. The player with the highest number of harvested fruits wins the game. Although the rules and constraints for playing this game were not stated by the students, they did connect their game to programming puzzles where a player earns a score for each correctly answered puzzle question, which implies a successfully harvested fruit.

#### 4.2.2 Playtesting co-designed mini games, prototype evaluation, and feedback

The playtest process began by asking each group to submit their co-designed concepts to the researchers after three weeks of OCD activities. Their submissions included designs, game scenarios, puzzles, and prototypes. These submissions were first blinded (anonymized) and shared among the groups for playtesting and peer reviewing. In other words, the groups peer-reviewed each other based on the guidelines provided by the researchers regarding the goals for playtesting and peer reviewing. For example, the participants were asked to focus on the clarity of the game scenario, contextual storyline, precise information on rewarding the player, appropriate use of game elements, motivating features, and educational content embedded in the game. Some of playtesters' remarks are given in Table 5.

Feedback from the peer reviews provided insight into the depth of knowledge these participants obtained and their expectation from each other regarding the design of a contextual educational mini game. In addition, the students were able to learn from one another at different stages of the co-design process, particularly from the peer review process.

**Table 5** Peer review of OCD prototype and evaluation by co-designers

| Group number (Gn) | Peer reviewers | Sample of evaluation remarks by student reviewers |
|---|---|---|
| Gn1 | Gn3 | "I don't understand what you meant by the question point and the puzzle point." "…in the first game I did not notice any form of reward for the player." **[Gn3]** |
| Gn2 | Gn1 | "very good idea" "This is an incredibly brilliant game Idea. I love it." **[Gn1]** |
| Gn3 | Gn2 | "… not able to get the info on time" "The game was not well explained." "The diagrams were not explaining the game, rather explaining the work through the game." "The write-up was not properly structured…" **[Gn2]** |

### 4.3 Students' experiences of OCD process for co-designing mini games

To answer the research question (RQ2) *"What are the experiences of students participating in an OCD of mini games to support their CT skills?"* we follow Moser and Korstjens' guidelines (2018) to present a content analysis of participants' responses to the interview conducted after completing the OCD process. The responses are the students' reflections regarding the knowledge gained and their experiences during and after the OCD process.

The students' reflections suggest that they gained several pieces of knowledge that made the exercise rewarding, although challenging, as claimed by some of the participants. For example, the following responses illustrate mixed feelings.

> the seminar was more of brainstorming especially the aspect of thinking of designing a game that helps one to understand programming… the experience was kind of challenging but was nice. **[P2]**
> **…**it's challenging to create games for education… **[P3]**
> My experience from the seminar was good. The seminar provided the opportunity for me to learn that games are not just all about the fun alone…but there's always educational knowledge that games usually pass onto the player…. **[P4]**

Regarding the expectation of the participants before participating in the OCD process and whether their expectations were met, their responses revealed that some participants did not know exactly what to expect but hoped to gain knowledge from the OCD process. For example, some participant responses were as follows.

> I don't actually know what to expect, but during the seminar, it was educative. I learned many things that I was not initially expecting. **[P1]**
> I thought that the seminar will be more of coding games, more of programming… but when we started, I discovered that it was more of games and

> co-design of games, then I felt excited since I do not know much of programming. **[P2]**
> Yes, my expectation for the seminar was to learn more about games because this was the idea the student coordinator gave to me…I thought we were going to be playing some games, but we ended up creating games. Its challenging to create games for education but I learned it during the activities in the seminar. **[P3]**

The interview specifically sought to know what learning objectives students gained from the OCD process. In other words, we asked the participants to describe a concrete take-home lesson from the OCD process. While some acquired collaborative skills, some mentioned learning about game elements and scenarios that seem unfamiliar to them before attending the seminar. Some responses from students in this regard are as follows.

> I learned that you can actually use games to teach many things because people learn differently and people learn faster using images and sounds, which is a better way to communicate certain concepts to students… this approach makes things stick faster in our minds and memory. **[P1]**
> I learned how to create smart learning system such as educational games that is easy to play and to teach students something. I also learned about elements of games… **[P2]**
> I learned about game scenarios, game elements, which I never knew, also, some platform used for creating games for different platforms **[P3]**
> Basically, I learned how to co-design games with fellow students…we brainstormed on ideas and collaborated in many ways to combine ideas for our games **[P4]**

The responses from interviewees shows that students had positively improved their co-design and collaborative skills after the OCD process. For example, one student asserted:

> even though some people in the group did not give their best input, which makes the workloads of group task to fall on a few… but it help me to learn a lot **[P4].**

Students generally expressed that the OCD process has positively affected their interest in educational games. Aside from the fun and excitement that students derive from games, they have been spurred through OCD process to design their own educational games. In fact, some anticipated designing educational games during their final year project.

## 5 Discussion

Previous studies have shown that co-designing digital mini games for educational purpose has proven to be a sound approach toward creating a learner-centered artefact (Havukainen et al., 2020). However, designing mini games through a co-design process is usually done in a face-to-face setting where the researcher meets with end users to participate in co-designing a product or artefact (Bonsignore et al., 2016). For example, Havukainen et al. (2020) recently explored a face-to-face approach for co-designing digital games with older adults and children. Similarly, Hjelmfors et al. (2018) co-designed with patients and health care professionals through a blended web-based and face-to-face approach to develop an intervention to improve communication health failure communication. This study designed and implemented an OCD process with CS students to create ideas, scenarios, and mini game prototypes that would later be developed into VR mini games to support CT and programming education. The study demonstrated how an OCD methodology was applied. The co-design process of mini games engaged twelve CS students at different levels of study in a Nigerian university. The commonality of the recruited students, i.e., they were all studying at the same university, helps make group collaboration easier. In addition, selecting students at different levels of study was a deliberate attempt to achieve an inclusive OCD process (Havukainen et al., 2020). Findings from this study are discussed in this section.

### 5.1 *How does OCD of contextual mini games with students in a Nigerian HEI work from the researchers' perspective?* (RQ1)

The descriptive analysis of the pre-OCD participation revealed several things. First, it was shown that most of the students who participated in the study had experience with online seminars and had even participated in an OCD activity before enrolling for this current study. This finding is surprising and makes the researchers wonder whether the students truly understood the meaning of the term "online co-design." The researchers had anticipated that since there a few OCD studies, most of the students would have little or no experience with it. It is possible that the students understood the term "online co-design" to mean "online collaboration," which probably is more familiar to them. This misunderstanding could be possible since their response was given before the actual seminar commenced. The researchers only provided a detailed explanation of the term "online co-design" and its objectives during the online seminar. The OCD objectives entail thinking, conceiving, and creating contextual mini game prototypes to assist students in acquiring CT skills.

As shown Section 4.1, Table 2, most of the students were used to playing games, and their experiences with different games were useful in making meaningful contributions toward co-designing contextual digital mini games. This finding aligned with Grover et al. (2020) where participants in the OCD for teacher's professional development were already familiar with the CS topic for which its curriculum was co-designed. In our study, the participants had the opportunity to brainstorm iteratively, discuss objectively, and negotiate their wish lists of game elements and features during the OCD process (Laine et al., 2020). The game elements wish list activity was initiated by the individual students and later extended to the group to allow for exhaustive deliberations on what users consider suitable for the mini games.

In addition, students were very eager to participate in the OCD process, as revealed by the results. Although their expectations before or during the OCD process were not explicitly known, their responses to the survey administered prior to the seminar showed that they had a strong motivation and were eager to participate in the OCD process. This result is expected since students voluntarily gave their consent to participate in the study and actively responded to our requests to participate in this study. While the students were hoping to learn new things during the OCD process, they did not expect to identify new areas in CS. This finding suggests that the students were probably familiar with CT topics and may have been taught the principles of CT in earlier completed courses.

Our investigation showed that students found “recursions” to be a very difficult programming topic to understand. This finding aligned with that of Anyango & Suleman (2018) who revealed that recursion and arrays are difficult programming topics for many novices. In addition, this finding provides useful insight in terms of supporting the authors’ intention to provide SLEs to aid students in understanding CT concepts, including recursion, in the context of Nigeria. In other words, when designing a smart learning environment to teach basic CT principles to improve students understanding of programming topics, the authors would ensure that part of the learning objective would include teaching and learning about problem abstraction and recursion concepts, which is lacking in previous VR application to gain CT skills (Parmar et al., 2016).

In addition, the output from the OCD, as discussed in Section 4, shows that the students learned CT by thinking of conceptual and contextual game scenarios and stories. This method of teaching has been acknowledged to make learning through experience useful to students (Kolb, 2014). Besides, students used familiar stories within their context to create mini games (Eckardt & Robra-Bissantz, 2018). In addition, OCD activities, such as playtesting of co-designed mini games, prototype evaluation, and feedback, shows potential to allow students to gain creative and constructive ideas for designing educational mini games (Jong et al., 2010). Playtesting would ensure that issues arising from the designed prototype that did not fit the desire of end users could be discovered (Bonsignore et al., 2016). This discovery provides feedback to improve the mini games. In this study, the playtesting conducted at this stage of the design was minimal since the prototypes designed were still at a very low fidelity. Thus, the playtesting was intended to provide a general evaluation of what users perceive fits their expectations rather than to engage users in serious gameplay or deep interaction with game elements.

### 5.2 *What are the experiences of students participating in an OCD of mini games to support their CT skills?* (RQ2)

The study generally revealed that students gained CT skills during the OCD activities, even though they indicated that the process was challenging (Walsh et al., 2012). The students felt that the OCD activities were challenging because they made them "think" and develop a game scenario. For example, the two major outputs of the co-design process in the online environment shows how the students learned to conceptualize problems and connect them to contextual scenarios to create mini games. Therefore, the students were able to gain CT skills (problem identification, abstraction, and algorithmic thinking) through the OCD process, which is in line with the findings of a previous study (Malik et al., 2019).

Moreover, the result from the interviews conducted after the OCD process shows that the students gained new experience, such as game elements and how to connect those elements to create mini games. In addition, the students developed more interest in educational games and expressed their interest in developing mini games in their study projects. Different from the work of Grover et al. (2020), the findings from this study regarding its impact on the students' learning outcomes suggest that engaging students in designing something that is useful to their learning can improve learning achievement and provide inputs for creating a student-centered learning environment. Therefore, a student-centered OCD approach to developing educational tools to teach CS topics can improve students' learning experience than a teacher-centered OCD approach.

### 5.3 Lesson learned from co-designing mini games in an online environment in the Nigeria context

In this section, we discuss the authors' experiences, lessons learned, and provide recommendations for educational game designers and researchers adopting the OCD method. The methodology deployed in this study provided insights regarding the feasibility and suitability of an OCD process within the context of a developing country. Implementation of OCD is an important step toward creating an alternative co-design process for designers and researchers whose stakeholders are in "difficult to reach" locations owing to certain circumstances. Particularly in the African context, it could be assumed that OCD is rarely feasible considering infrastructure challenges, such as the cost of internet bandwidth, uncertain electricity supply to power the devices used for OCD, and limitations in terms of students' willingness to participate in week-long activities in the online environment. However, our experience shows that a methodological approach that is well-planned and defined can be suitable for such a context. Especially in this current era of efficient, easy to use, and even free online collaborative tools, such as Zoom, Google Meet, and WhatsApp, user-centered co-design processes can be conducted anywhere in the world.

While implementing the OCD methodology (Fig. 3), several noteworthy lessons were learned. These lessons could be useful to researchers, designers, educators, and other stakeholders interested in conducting a similar study in a contextual situation similar to this study. We discuss these lessons in five stages, which include (i) planning and engaging, (ii) exploring, (iii) designing, (iv) discussing and deciding, and

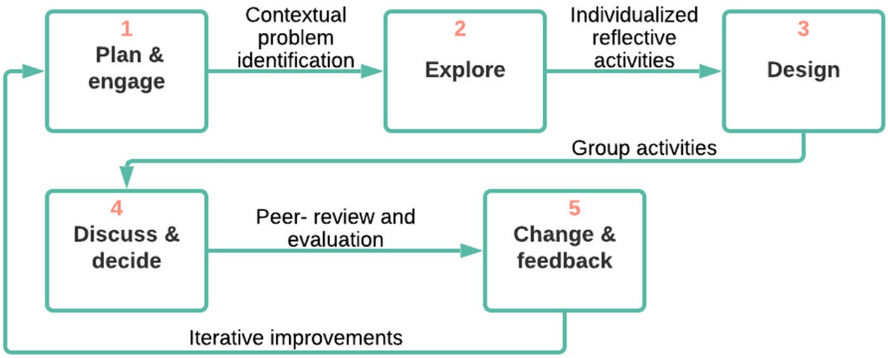



**Fig. 9** Process flow of the five-stage implementation of OCD process

(v) changes and feedback stages. To better present these stages, we have provided Fig. 9 as a process flow and connects it to the lessons learned from the implementation of the OCD methodology. That is, the activities at each stage serve as input to the next stage. The stages presented in Fig. 9 is followed to explain researchers' experiences from implementation of the OCD process, lessons learned, and recommendations that may be useful to educational game designers and researchers who may adopt the OCD method in future research.

**Planning and engaging stage** From the researchers' experience, the applied OCD process was successful in the Nigerian context. However, problems regarding expensive internet bandwidth, inconsistent electricity supply, and lack of full commitment by some participants some of the contextual issues experienced. We mitigated these challenges by providing internet connectivity and electricity to motivate the participants, specifically during the online seminar. Hence, we recommend that during the planning and engaging stage, researchers should identify and recruit co-designers who are willing to fully participate in the OCD process. We also recommend that researchers should make provisions for basic facilities, such as internet connection that participants might need during the OCD implementation.

**Exploring stage** During the exploring stage, the basic equipment and technology required to conduct the OCD process were arranged, tested, and confirmed to function effectively. This initial confirmation was possible by running a test session between the OCD facilitators and selected participants using the Zoom platform. Although a few challenges that could interfere with online collaboration were identified at exploring stage, steps were address them before the main OCD process began. Therefore, we recommend that researchers should conduct an initial needs assessment to determine the type of equipment/platforms that work well (Walsh et al., 2012). For instance, the internet strength and the online communication platform must be simulated to ensure they are fit for OCD implementation.

**Designing stage** To make the designing stage a collaborative experience, the participants were grouped (Huizenga et al., 2019). Each group was limited to four members. Group activities within the designing stage included brainstorming on game elements wish list, ideation about contextual game scenarios and stories, creation of education mini games (puzzles), paper and mock-up designs, and presentation of concepts. Our experience shows that small groups can achieve quality collaboration. Inclusive collaboration can be enhanced if every member contributes to the group tasks. Hence, we recommend that researchers should begin by conducting a brief seminar where participants are introduced to the concept, goals, and objectives of the activities. Afterwards, participants should be grouped to allow for effective collaboration (Bonsignore et al., 2016).

**Discussing and deciding stage** During the discussing and deciding stage, co-designers presented their concepts at the group level. Each group evaluated another group's design and provided feedback based on the guideline that researchers had provided. The goal of the peer review is to obtain a users' perspective regarding what they considered suitable within the mini games by playtesting the paper prototype (Eckardt & Robra-Bissantz, 2018). Our experience shows that students learn from each other's concepts by providing comments (appraisals) based on their expectations of educational mini games. Therefore, it is recommended that OCD study allow co-designers to peer review themselves at group level based on their expectations (da Costa et al., 2017). This way, they could learn more from one another's ideas and contribute by presenting their individual point of view. We recommend that playtesting of prototypes should involve peer reviews.

**Changes and feedback stage** In the changing and feedbacking stage, comments from the co-designers (Table 5) formed part of the requirements for the ongoing second phase of the design process. Our experience shows that changes and feedback are an essential component of OCD where unforeseen situations may be accommodated at any stage of the OCD implementation. The OCD process allows for feedback at any stage. Although the output from one stage could serve as the input of the next stage, we recommend that implementation of the OCD process should be flexible enough to allow for scalability and changes that may arise.

### 5.4 Study limitations

This study was not without limitations. In terms of the procedure and methodology used, OCD did not give researchers the opportunity to completely monitor participants' activities remotely, which defeats the aim of mentorship and creates a barrier for a supervised collaborative design. Some potential solutions future studies could provide to alleviate this issue is to, for instance, ask the students to record all co-design activities or use a web-based co-design tool that automatically records all activities. The number of participants recruited for this study was small. This small sample size limits the extent to which our results can be generalized. While we tried to mitigate this limitation by adopting the interview method to gather more in-depth data, future studies should consider recruiting more students. In addition, issues of scalability might occur if the same OCD process is applied with more than 100 participants. Another limitation is the way playtesting of the designed mini games was conducted. Users only evaluated the low-fidelity paper and mock-up prototypes. They could not use the complete digital version of the prototype. This creates a lack of interaction with the game elements and features, which limits the user's experience.

## 6 Conclusion and future work

This study employed an innovative approach of OCD process to develop educational mini games through which students can gain CT skills, and the resulting prototypes are being developed into a VR based mini games environment to support the understanding of CT concepts. This intended VR application is aimed at supporting teaching and learning of CT at HEI in the context of Nigeria; however, it is envisaged to be relevant to students in all contexts since understanding of CT concepts, such as recursion, is still considered problematic for novices globally. The OCD process was developed to suit the situation where a face-to-face meeting between researchers and other stakeholders involved in co-designing artefacts became difficult. This study provided a thorough explanation of how the OCD process was followed to design contextual mini games prototypes (paper and mock-up based). Online platforms, such as the Zoom and WhatsApp, played the major role in implementing the OCD process. Analysis of participants' pre- and post-experience regarding seminar participation, co-design experience, gameplay, and games elements are presented in the study. One of the learning points for the researchers is how contextual games can emanate from the students being the co-designers and users of the mini games. This study highlighted five main stages for implementing the OCD process based on the researchers' experience. These stages are part of the researchers' contribution to the existing knowledge in terms of methodology and practice of co-designing mini games in online spaces.

This study reported part of the steps of authors' long-term plan of developing a learning environment to support CT skills in the context of Nigeria. The learning environment would provide a gamified approach for learning abstract programming concepts, such as recursion, through immersion in a VR environment. In addition, the study contributes to existing research in terms of co-designing educational mini games in several ways. First, the study established a theoretical foundation for designing a GBL application and connects these theories to guide the researchers' future study. Second, a methodological approach for conducting an OCD process was designed and implemented. Third, the results gave insight into how students conceived contextual mini games to solve CT and programming concepts. Fourth, the study outlined five stages of implementing the OCD process as a way of explaining the researchers' experiences and lessons learned. The recommendations provided in this study were based on these lessons and can serve as a guide to researchers who are carrying out similar studies in the future.

Future work will attempt to address the limitations highlighted earlier by investigating how to teach CT through the co-design process with a scaled number of participants in face-to-face and online settings. This future direction will provide the opportunity to conduct a comparative study to gain more insight into what works and what does not work within the context. Currently, we are finalizing the implementation of a VR application prototype, making it a collection of high-fidelity VR mini games to support students understanding of CT. A screenshot of this VR application of mini games is shown in the Appendix. Once finished, the authors would proceed to experiment and evaluate this prototype with CS students. In addition, the authors would try to investigate students' opinions about the perceived difficulty of CT and programming concepts after participating in the experiment.

## Appendix


Screenshot of a VR-based *Mount Patti Treasure Hunt* mini game co-designed by the students. Left, the climbing progress made by the player and a falling stone that could crush the player. Right, a puzzle the player must solve to avoid being crushed by the falling stone and progress to the top of the mountain.

**Questionnaire items administered prior to OCD activities.**

**Course of study:**

| | | | | | |
|---|---|---|---|---|---|
| Computer Science | ☐ | Computer Engineering | ☐ | Information Science | ☐ |
| Library Science | ☐ | Mathematics | ☐ | Others | ☐ |

**Questions on prior knowledge and experience in participating in seminars**

| S/N | Items |
|---|---|
| 1 | I have participated in an online seminar |
| 2 | I have participated in an online co-design process |
| | **Questions on game and game design** |
| 3 | I am an active player of games |
| 4 | I play game to gain more fun |
| 5 | I play game to gain new knowledge or learn new things |
| 6 | I have frequently participated in game design |
| 7 | I am familiar with the elements of game |
| 8 | I am aware of how game elements operate |
| | **Questions on expectation from participating in the OCD process** |
| 9 | I am eager in participating in the seminar because the purpose in the invitation notice was clear |
| 10 | I am eager in participating in the co-design process because I like to collaborate and share knowledge |
| 11 | I expect to learn new things in the co-design seminar |
| 12 | I am hoping that the co-design seminar will help me identify new areas of computer science |
| 13 | The seminar will provide me the opportunity to design my own game |
| | **Question on ease/difficulty in understanding programming topics** |
| 14 | In each of the programming topics, choose how easy or difficult they are based on your experience:<br>1. Programming Basics<br>2. Variables<br>3. If Statement<br>4. Loops<br>5. Functions<br>6. Methods<br>7. Recursions<br>8. File and Exception Handling |

**Interview instrument for participants of online co-design process**

1. Tell me about your experience during the workshop.
2. What was your expectation before the workshop, and was this expectation met?
3. What is the objective of the workshop (what exactly did you learn)?
4. Is your knowledge of co-design improved in any way? How?
5. Tell me about your experience in co-designing within the group.
6. Did you contribute in any way? Share with me how you contributed, and lesson learned?
7. What other things have you gained from the co-design process with your colleagues, for example, brainstorming about the ideas on games, designs, and paper prototypes?
8. How has this exercise of the co-design process affected your interest in educational games?
9. How has your knowledge of VR improved?
10. Amongst the game elements, you have outlined from the group task, which is most important to you and why?

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**Declarations**

**Competing interests** The authors declare that they have no competing interests.

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