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Designing Exploratory Serious Games with Learning Supports

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Öğrenme Destekleriyle Keşfettirici Öğrenme Oyunları Tasarlama

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Abstract

Serious games are computer games with learning objectives, and present stimulating contexts with interactive, engaging and immersive activities. The brain wave analysis and the neuro-functional correlates of game-based learning revealed that game-based learning is a powerful tool to enliven processes of learning through providing reward and emotional engagement. Implementing a game design model that effectively incorporates game mechanics and pedagogical mechanics is essential in the development of a serious game as an interactive learning environment. The current literature provides many serious game development framework, however, no single framework is sufficient to cover interdisciplinary field of exploratory serious games. This study aimed to develop a framework for designing exploratory serious games. In order to ensure that learners would attain objectives of the learning unit in the game, the proposed conceptual design framework was based upon (a) Kiili's experiential gaming model (2005), (b) 4C/ID instructional design model (Van Merrienboer, Clark, & de Croock, 2002), (c) ARCS motivation model (Keller, 1987), and (d) Activity theory (Engeström, 1987). The framework pays particular attention on learning support mechanisms of the game because students may have difficulty in, miss or avoid learning curricular content of an exploratory serious game when they focus on merely game mechanics. Finally, the study also stresses and discusses enhancing players' flow experience and enriching adaptability of the game through design of task regimes.

Article Info

Keywords: Serious games, exploratory learning games, learning support, instructional design

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Öğrenme Destekleriyle Keşfettirici Öğrenme Oyunları Tasarlama

Öz

Dijital öğrenme oyunları eğitsel hedefleri önceleyen ve öğrenciyi cezbeden bağlamlarda etkileşimli, bağlayıcı ve sürükleyici etkinlikler sunan ortamlardır. Oyun-tabanlı öğrenenlerin beyin dalgaları ve sinir bilimsel örüntüleri konusundaki araştırmalar, oyun-tabanlı öğrenmenin sağladığı ödül ve duygusal bağlayıcılık özellikleri ile bilişsel süreci etkinleştirmek için güçlü bir araç olduğunu göstermektedir. Oyunlaştırma öğeleri ve eğitim bilimsel değişkenlere ilişkin öğelerin başarılı bir şekilde bir arada kullanılması gerekmektedir. Söz konusu bütünleştirmeyi sağlayarak öğrenme oyununu etkileşimli bir öğrenme ortamı yapan temel unsur oyun tasarımında kullanılan modeldir. Alan yazında çok sayıda öğrenme oyunu tasarım modeli olmasına rağmen, disiplinler arası bir eylem olan bilgi keşfettirici öğrenme oyunları tasarımında tek bir model tek başına yeterli olamamaktadır. Bu çalışma, bilgi keşfettirici öğrenme oyunları tasarımında kullanılabilecek bir bütünleşik model geliştirmeyi hedeflemiştir. Çalışmada, öğrencilerin belli bir dersin hedeflerine bir öğrenme oyunu içinde ulaşmasını sağlamak amacıyla, aşağıdaki modeller bir arada ele alınarak bütünsel bir model önerilmiştir: (a) deneysel oyun modeli (Kiili, 2005), (b) 4C/ID öğretim tasarım modeli (Van Merrienboer, Clark ve De Croock, 2002), (c) ARCS motivasyon modeli (Keller, 1987) ve (d) Etkinlik kuramı (Engeström, 1987). Önerilen bütünleşik model, öğrencilerin sadece öğrenme oyunu içindeki oyunsal mekanizmalara odaklanarak oyundaki konu alanı içeriğini ihmal etmelerini ve öğrenme zorluğu yaşamalarını önlemek amacıyla oyundaki öğrenme destek mekanizmalarına özel önem vermektedir. Ayrıca, öğrenme oyunlarında tasarlanacak görev setleriyle öğrencilerin etkinlik akışının artırılması ve oyunun uyarlana bilirliğinin geliştirilmesine dönük bir dizi öneri sunulmaktadır.

Makale Bilgisi

Anahtar Kelimeler: Dijital öğrenme oyunları, açınsayıcı öğrenme oyunları, öğrenme desteği, öğretim tasarımı

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Introduction

People spend long hours for playing both conventional or digital games. For example, senior citizens play card games in coffee-houses, or teenagers spend long hours in front of their digital devices to play different types of games. Many school children spend longer time periods for playing games than doing their homework (Adelantado-Renau et al., 2019). Further, playing a digital game or compulsively checking of social media for new posts for a large amount of time per day is commonly observed among students (Gomez, Devis, & Molina, 2020). What makes students at different ages spend so much time on games, but not on curricular activities? What are the shortcomings of interactive learning environments that cannot attract students as much as games or social media to spend enough time on tasks?

Brain based research using objective measurement techniques shed some light on this issue. Both checking of social media and playing games long hours "(are considered as samples of potentially problematic device use) arouse a user's brain, "causing the intermittent release of the neurotransmitter dopamine" (Haberlin & Atkin, 2022; p. 2). Dopamine and oxytocin are two hormones that can act as powerful agents of change in the brain (Berke, 2018). The endocrine system releases dopamine when one wins or is rewarded (Greipl et al., 2021). The brain is running along producing one's thoughts, feelings and actions. If one chooses an action that is successful one gets a flood of dopamine to the brain. The second powerful hormonal agent in the brain is oxytocin triggered by physical contact with another individual, or by the memory of closeness to another or even by imagining future closeness to another (Oxford, Ponzi, & Geary, 2010). For example, multiplayer games with a cooperative or collaborative play element constantly trigger the oxytocin hormone through their game tasks that may be achieved in collaboration with other players of the game (Krarup & Krarup, 2020). The brain enjoys these two hormones and records this as a desirable pattern to reactivate in the future (Haberlin & Atkin, 2022). Further, cortisol is a steroid stress hormone triggered by the brain in response to stressors, along with others it impacts memory (Aliyari et al., 2018). However, when it comes to the influences of serious games on students' accomplishment in a curricular unit, there are varying research results providing evidence for both positive as well as negative effect on learning; despite the fact that in most of those studies, the serious games were welcomed and found enjoyable by the students.

Some studies using comparisons of experimental and control groups showed positive effects of games on students' learning mathematics, particularly mathematics fluency in grade 1-4 (Fraga-Varela, Vila, & Martínez, 2021), algebra in high school (Umbara, Munir, Susilana, & Puadi, 2021); electrical circuit in elementary science (Noh, Mohamed, & Zin, 2021), light and sound in 5th grade science (Toprak, Akcay, & Kapici, 2021), and at a college level, foreign language vocabulary and history learning (Chen & Hsu, 2019), and concepts of object-oriented programming (Abbasi Kazi, Kazi, Khowaja, & Baloch, 2021). Along with studies showing positive effects of serious games on learning different domains at different levels, there are studies showing negative effects of them on learning. For example**,** Newbery, Lean and Moizer (2016) conducted a quasi-experimental study with college students majoring management, the study participants studied entrepreneurship within a game (SimVenture) for three weeks, control group participants studied the same content without the game. The analysis of pre and post test data revealed that whilst %32.4 of experimental group students performed positive improvement, %11.2 of them did not show any improvement and %56.4 of them performed negative improvement. In another study (Cowley, Fantato, Jennett, Ruskov, & Ravaja, 2013), two groups of college students studied conflict negotiation with an experiential game (Peacemaker) in two modalities. Learning performance of the groups was identical and poor. The type of elaborative discussion activities right after the game playing was reported as the cause for the negative results. They advised organizing learning strategies that do not impede flow of the lesson embedded in serious games. Further, computer science students studied code debugging in C++ programming with a game (RoboBUG), Miljanovic & Bradbury (2017) reported that the game failed to help the students' learning, and suggested integrating a hint providing module to the game.

Problems in Learning with Serious Games

Virtual worlds represented in serious games have constraints compare to physical worlds. Though users can manipulate screen objects in virtual worlds through a mouse, a keyboard, a joystick, voice, eye movement and fingers on touch-screens, in these settings they cannot experience similar feelings of touch and manipulation as in a physical world. User and screen-object interaction in a serious game compared to a physical world is indirect, rather than direct; hence the interface of a virtual world plays the role of a moderator. Research in learning sciences stress that students' experience of using their body movement in learning processes is important (e.g., Shapiro & Stolz, 2019). Students' physical activities in a virtual environment may not be reduced to only movements of lips, fingers and hand; but their activities should be in harmony with behaviors required in that virtual environment. According to Shapiro and Stolz (2019), such distance between cognition and behavior would disturb students in a learning process. A reverse relationship between a serious game player's expected cognitive load and effects of that game on learning was reported (Cowley, Heikura, &

Ravaja, 2014), therefore consideration of simplicity principles in design of serious games is recommended. Further problems with serious game research involves the followings:

- Short periods of observations and interventions in experimental studies,
- Coverage of narrow content domains in those tested serious games,
- Conduction of many studies based on only practice based activities,
- Undesired novelty effects of serious games on learning,
- Lack of reflection of different knowledge representations in applications,
- Lack of integration of learning mechanics,
- Over-coverage of game mechanics in the applications,
- Insufficient coverage of problem formation and manipulation of abstractions in learning units,
- Undermining students' self-reflection skills and neglecting elaboration scaffolds in design of support mechanisms,
- Insufficient consideration of cognitive load issues in instructional design.

A recent comprehensive meta-analysis of 46 meta-analysis of research conducted on serious games between 2016-2020 (Metwally, Nacke, Chang, Wang, & Yousef, 2021) summarized deficiencies of serious game research. The analysis showed that many studies lacked theoretical frameworks, had insufficient and un-generalizable findings regarding the effects of design, development and testing of serious games on learning. More studies focusing upon validation of theoretical frameworks, different design and development models were advised.

Problems with Serious Game Design Frameworks

A commonly implemented framework for serious game design, Kiili's experiential gaming model (2005), is based on Kolb's cyclical model with four main stages in learning. It starts with concrete experiences at which the students observe and reflect. The students conclude something on the basis of observations and reflections. Then, they form generalizations and transfer knowledge to other contexts or scenarios. At the final stage, generalizations are tested through experimentations and experiences. Kolb's model has been criticized as being too simplistic: According to, for example, Holman, Pavlica and Thorpe (1997) this model neglects the complex process of learning where action, experience, reflection and thinking are interconnected. Further, Miettinen (2000) argues that Kolb's model underestimate effects of the social interaction in the learning process. Based on such criticisms, Rooney (2012) comprehensively examined derivations of the experiential model and proposed a theoretical model with three main components of fidelity, play, and pedagogy. Similarly, Harteveld (2010) suggested the Triadic Game Design approach focusing on three dimensions as technology behind the game (play), learning objectives and learning sciences (meaning) and representation of the real world (reality). Both Rooney and Harteveld stress the importance of setting up a balance among these three components in the process of serious game design. However, how such balance would be achieved is not unveiled. These limitations may be resolved through the use of a sound instructional design model.

Amory and Seagram's (2003) Game Object Model (GOM), based on object oriented programming concepts, links pedagogical theories with game design principles. Primary components of GOM are categorized under titles of players, story, game space and social space. Clark (2020) criticized this model as being too complex and rigid for serious game designers. Besides, the Serious Games Conceptual Framework proposed by Yusoff, Crowder, Gilbert, and Wills (2009) and the Six Facets of Serious Games Design model (Marne, Wisdom, Huynh-Kim-Bang, & Labat, 2012), compared to many other frameworks, did not add something new to Kiili's interpretations of experiential model. Further, Learning Mechanics to Game Mechanics (LM-GM) Mapping Approach (Arnab et al., 2015) provides a more comprehensive set of pre-defined game mechanics and pedagogical elements. However, as in many serious game design proposals, LM-GM approach also lacks a sound instructional design model which clearly guides practitioners.

Recently, Jaccard, Suppan, Sanchez, Huguenin, and Laurent (2021) proposed a new framework considering multidisciplinary nature of serious game design which puts collaborative dimensions into the front of design, development and assessment. The framework highlights design elements under five main categories: (a) Context and objectives, (b) Game design, (c) Learning design, (d) Mechanics, and (e) Assessment. The authors noted that co.LAB framework is generic enough that if one design element is missing, designers can easily integrate it to the model, but nevertheless how such incorporations of elements (e.g., how different types of instructional support should be integrated into the game design) would be handled is ambiguous. Moreover, Ishaq, Rosdi, Zin, and Abid (2022) recommended a serious game design model considering cultural context by integrating the following five elements: academic requirements, educational settings, socio-cultural aspect, gamification constructs, and usability guidelines. This model merely focuses on language education, nonetheless, fails to specify many of the pedagogical mechanics of serious games, it simply concentrates on education level and mode of delivery in the component of educational settings.

Many of serious game design frameworks are, first, committed to specific types or specific domains such as health (for example see Verschueren, Buffel, & Vander, 2019). Second, many frameworks contain motivation as a basic component of the model, but they fail to guide construction of motivational elements into serious games (e.g., Jaccard et al, 2021). Third, an essential component in instructional design is cultural context which is not sufficiently taken into consideration in many frameworks (e.g., Amengual, Jaume-I-Capó, & Moyà-Alcover, 2018). Fourth, many frameworks oversimplify complexity of learning, and therefore often prioritize the entertainment aspect over the learning content. As a result, complexity of learning content may lack depth, which may deter effectiveness of the learning experience. Fifth, some frameworks follow a rigid structure, limiting customization and adaptability to different learning contexts, different instructional approaches or individual learner needs. This may lead to a one-size-fits-all approach that may not cater to diverse educational requirements. Sixth, some frameworks simplify learning environment design to escape from resource-intensive (e.g., requiring specialized skills, time, and financial investment) serious game design. Seventh, some frameworks focus very much on game mechanics. Learners may be motivated by the game mechanics and rewards rather than genuine interest in the subject matter, leading to limited knowledge retention and transfer outside the game environment. Eighth, some frameworks neglect lack of integration with daily classroom activities. This can create a disconnect between serious games and established educational structures, limiting their reach and impact. Finally, some frameworks put very much emphasis on practice of knowledge and skills before they are understood. This leads practitioners fail to explicitly differentiate learning activities for understanding and for practicing learnt content.

It's important to note that while these criticisms exist, serious games, designed and developed following firm learning and teaching frameworks, can be effective instructional tools with fast and timely delivery of feedback, interactivity, flexibility and adaptation (Van den Hurk, Meelissen, & Van Langen, 2019). The field of serious game design is evolving, and addressing the above criticisms may contribute to the improvement. Hence, considering aforementioned problems of the serious game design, this study aims to overcome the shortcomings of the current design frameworks, and hopefully fill the gap in particularly design of exploratory serious games. With the aim of enabling students to attain objectives of the learning unit in the game, the conceptual design architecture was centered on (a) Kiili's experiential gaming model (2005), (b) 4C instructional design model (Van Merriënboer et al., 2002), (c) ARCS motivation model (Keller, 1987), and (d) Activity theory (Engeström, 1987).

Exploratory Learning Environments

Direct instruction delivered by a human tutor or a computer based application does not always fail to get students' continuous attention and to keep students on tasks leading to learning. In fact, laborious meta-analyses (e.g., Hattie, 2009) reveal that direct instruction has remarkably large effects on achievement in a wide variety of fields. Effects of direct instruction may be a function of different moderating factors (e.g., tailored instructional practices, expertise levels), research supports direct instruction compared to exploratory learning (Liem & Martin, 2013). That, however, does not disregard the constructivist view of learning through guided instructions in exploratory settings. For example, it is interesting for students to actively run simulation settings where both conceptual and procedural knowledge are reflected through screen objects and operators as well as through their interactions. In addition, providing students with opportunities to experiment, to make mistakes in a secure environment and to correct mistakes has been favored because students may reflect different viewpoints and approaches to develop conceptual change in the studied learning unit. Such thought-provoking settings may help students to develop knowledge elaboration skills and argumentative knowledge in the domain. An exploratory learning environment (ELE) is "an environment that supports learners in constructing their understanding about a specific subject through learner-driven reflective inquiry" (Rick & Lamberty, 2005; p. 180). It is the settings where learners can act as explorers to unveil hidden conceptual relationships, laws, principles and abstractions of a certain domain. ELEs typically provide learners with (multiple) representations that help discover and construct the domain knowledge: Students study multiple representations of information (digitized static and dynamic 2D/3D graphics, animation, simulation, text, symbols (abstract formulas), videos) to accomplish conceptual understanding and then to employ those multiple representations to reason, and to solve problems in the domain. ELEs give learners instruments to support more engaging and personalized learning experiences (Freitas & Neuman, 2009): Exploration denotes more occasions for learning, more social and interactive learning and better learner control over a learning environment and sharing, and practice of skills in a simulation or serious game.

Design of Exploratory Serious Games: A Blend of Models

In educational games, it is very likely that many students' primary interests would be to play the game in order to raise their score, get more badges, accomplish higher and higher levels at the game, or complete a task in a shorter period of time. One of the challenges to the instructional designers in building exploratory learning games is to create mechanisms and approaches with which students would pay enough attention to the learning mechanics of the game more than or as much as the game mechanics. To blend learning theories, learning mechanics and game mechanics in order to help learning a curricular content is critical, and outlined in Figure 1. There are different models in the literature for serious game developments, however, among them, experiential game design model (Kiili, 2005) may be one of the models which best meets criteria of interactive learning environments, provided that a sound instructional design model sheds light on creation of learning experiences and learning supports. This model is successful in corresponding “components of experiential learning theory and game mechanics” to get students have “flow experiences” in interacting with a serious game. Experiential learning theory (Kolb, 1984) expresses the significance of both students’ direct experience with tasks and reflective thinking in the learning process. In Kolb’s experiential context, experience relates entirely to lived experiences in real life settings (e.g. in the factory). Nevertheless, in the current exploratory settings, experience may link to simulated experiences and ‘transactional’ learning (Maharg, 2007): As such, it is learning grounded on exchanges, i.e. tasks and activities, between actors in a simulation, game or virtual setting and between a student and her peers and perhaps teachers (Freitas & Neuman, 2009).

Flow experiences in students’ activities (Csikszentmihalyi, 2014), however, suggest that a student’s full involvement to activities would provide the best experience. An exploratory game aims to provide students with challenges related to a particular task scheme so that flow experience is observed. Flow experience in tasks should be taken together with ARCS motivation model for task designs because student motivations in learning many curricular content with abstractions are low. It has to be highlighted that while experiential game models present some guidelines to design serious games, this model doesn’t provide sufficient guidelines to design instructional tasks in exploratory serious games. For that reason, four components instructional design model (4C/ID model by Van Merriënboer et al., 2002) may suit well to design and organize instructional components or learning mechanics of exploratory serious games.

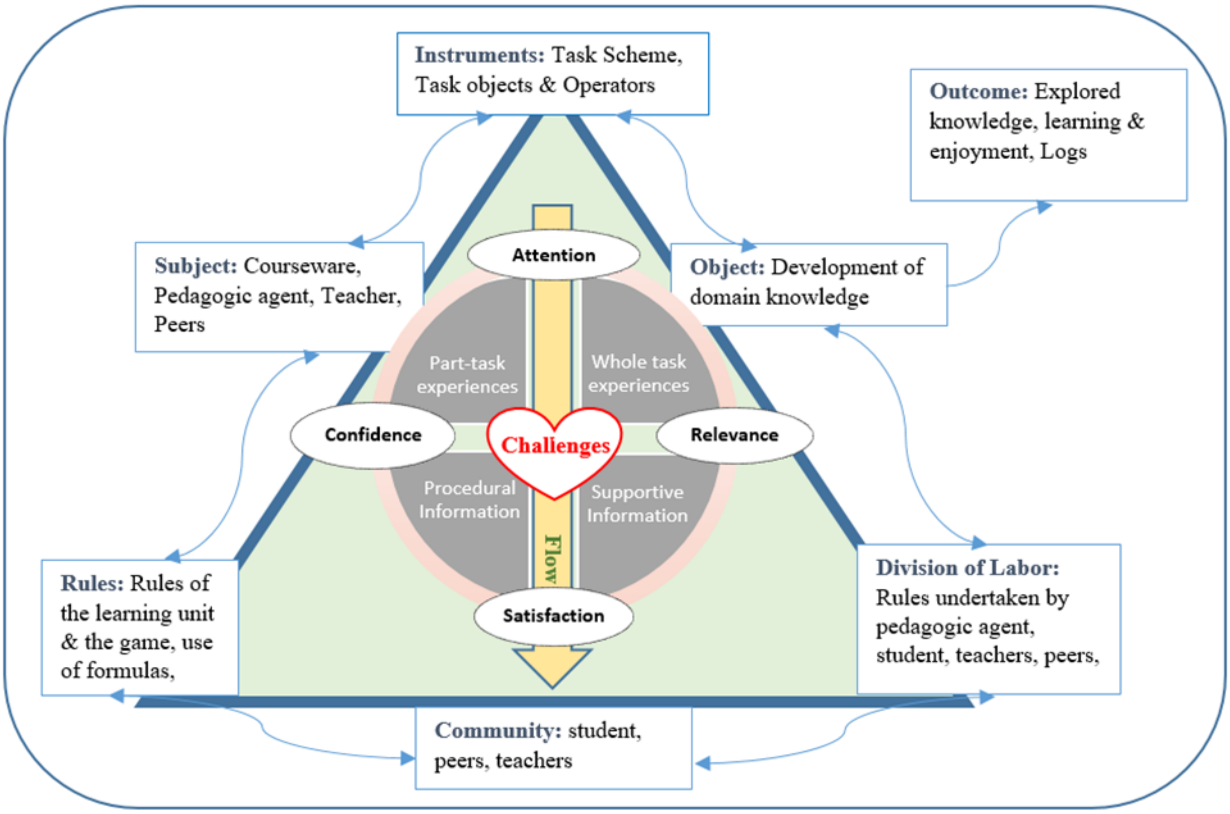

Figure 1. A blend of activity theory, ARCS motivation model and 4C/ID model

The following four components constitute the 4C/ID approach: Learning tasks, supportive information, procedural information, and part-task practice. This approach is comprehensive in the sense that complex learning units with integrative goals of knowledge, skills, and attitudes may be covered in the design. Following needs analysis of a learning environment and its components, this approach suggests creating learning activities organized in large size learning tasks, and learning tasks should be presented within real life related contexts and, if possible, within their authentic contexts. To understand how both context and tools (instruments) mediate continuous human activity, sociocultural psychologists proposed Activity Theory as a framework (Engeström, 1987). In the activity theory, subjects, community, objects, instruments, division of labor and roles are inter-connected components (Kaptelinin & Nardi, 2009). The meaningful context in a serious game is the mutual relationships between subjects (learner/pedagogical agent/peers/teacher) and that they act upon serious game objects as they are mediated by instruments, language, and sociocultural contexts (Engeström, 1987; Lazarou, 2011). Application objects in serious game are that "at which the activity is directed and which is molded or transformed into outcomes with the help of physical and symbolic, external and internal tools" (Engeström, 1993, p. 67). In essence, objects may be theoretical schemes as instructional objectives to be accomplished in a serious game, or physical objects, even abstracted concepts. Instruments are the concepts, physical or virtual tools, metaphorical machines, operators, artefacts or resources that mediate a student's interactions with an object. The community of a serious game refers to a student's peers who cooperate, collaborate and/or compete, pedagogical agent of the application and the teacher with whom the subject may share transformations in the game culture. "Communities mediate subjects' activity through serious game rules, scripts, roles, division of labor, and shared norms and expectations" (Akpınar & Turan, 2014; p.257).

Learning tasks in 4C/ID model should get students to easily relate students' prior knowledge and experiences, both formal and informal, with the new knowledge, skills and attitudes covered in the learning unit, and to build a model of knowledge patterns covered. Learning activities reflected through learning tasks should be categorized and ordered according to their cognitive difficulty level. Presentation order of the tasks, then, would be in order of simple to difficult.

Supportive information and procedural information are presented during learning experiences. In this model, supportive information is suggested to be presented when students are exposed to complex and extra ordinary problem tasks. Procedural information refers to information regarding how a routine task should be handled. Furthermore, a learning activity is to be designed within a form of a large enough learning step, practice and reinforcement activities are suggested to be designed within a form of small learning steps.

For the nature of learning activity and learning step size, the ARCS model suggests, as the acronym suggests, four different strategies. How instructional designers should reflect those strategies into serious game applications is briefly explained below:

(i) Attention Strategies: The application should present facts that initially challenge students' earlier experiences, and display graphical representations of set of ideas or relationships, if necessary use analogies and metaphors, to concretize the ideas as much as possible. Presentations of tasks conveying domain knowledge must be embedded in attention-grabbing contexts. For example, to learn a particular procedure, some tasks may focus on operating a machine representing the procedure; whilst some tasks may focus on breakdowns of that machine, setup of that machine or partially completing the task without the machine because a failure in the interaction of a device will be a more thought-provoking context to students than the device itself. Sense of humor in task designs and in instructional support or scaffolds provided shouldn't be neglected.

(ii) Relevance Strategies: The application should use analogies familiar to students' earlier experience, and state clearly the present and future value of learning the curricular content of the game wherever appropriate, for instance in instructional support text. Further, through students' task accomplishment in meaningful alternative methods, the application should allow students model correct behaviors of professionals working with knowledge and skills covered in the unit.

(iii) Confidence Strategies: The application should incorporate plainly stated learning goals into tasks, and, if possible in the context, present self-evaluation tools and the criteria for assessment of performance. Also, the application should structure materials on a gradually increasing difficulty level; that is, with Keller's term, provide a "conquerable" challenge. Instructional support should help learners how to develop a work plan which may result in accomplishing a goal. Learners' success through effort rather than chance should be credited, and different task regimes should be provided to get learners to accomplish tasks with decreasing support in learning and practicing skills. Moreover, along with the suggestions of 4C/ID model, the ARCS model basically enlighten design and development of task schemes in a serious game. A task scheme is a set of tasks requiring learners to complete a number of activities to explore a fraction of the learning unit. Because each sub-set of a learning unit has different depth and construct of knowledge, possibly requiring different cognitive activities such as selection, organization and integration, the instructional designer has to configure, group and order, from easy to difficult, learning activities.

(iv) Satisfaction Strategies: The application should provide facilities for learners who mastered a set of tasks to help others who have not mastered them, and provide frequent reinforcements in learning a new task and intermittent reinforcement as learners get more competent at a task. Also, informative and motivating feedback following task performance must be delivered. Finally, efforts and successful task performance must be rewarded by both means of learning and game mechanics.

An Exploratory Serious Game: Curious Robots

Some facilities of an exploratory serious game designed by following most of the principles outlined above may be observed in one of our exploratory serious game (Akkaya, 2019; Akkaya & Akpınar, 2022), Curious Robots. It was developed as a research tool, and designed to teach the basics of object oriented programming (OOP) and computational thinking, embraces an element that supports students to construct their own code blocks in line with the requirements of their missions as a game play experience. Primary characteristics of the game is that the fundamental concepts of OOP are incorporated into the game story. Fantasy components such as metaphorical (invented) gears and planets were used to incorporate OOP concepts into the game story since the use of fantasy components may improve students' learning (Garris, Ahlers, & Driskell, 2002). Employing stories is among the fundamental constituents of the process of a serious game design (Rollings & Adams, 2003): Fairy tales or stories establish the ground setting for games, and facilitate the aggregation of small tasks into a main goal. Students' role in the game environment is to work in the Turkish Space Agency (TSA) as an engineer responsible for programming robots. Events of the game takes place in 2048 when the world is on the threshold of an emergency because of global warming, and researchers in the TSA are searching for a new planet for humans to settle. The game is a type of simulation games where students first construct their own robots and program them to discover a fictitious planet, named Asgard, and to decide whether or not the planet is convenient for human to settle. There are eleven different activities with a gradual increase in the level of difficulty. During the course of the game, students are provided with directions about their task through a pedagogical agent (PA) in a task slot located on the screen. The PA in this environment has an imminent role to play in the incorporation of OOP concepts into events of the game by expressing the story and presenting information about the learning activities. The PA provides feedback and storified information in a task handled in the learning game setting, also it boosts learners' motivation and leads to deep learning (Moreno, Mayer, & Spires, 2001). Moreover, the setting delivers hints and immediate and/or delayed feedback, both visually and verbally, about students' mistakes in a mission. The first mission of the story requires students to construct a chip with the descriptions of behaviors of a robot which is a tool in the investigation operations. The chip in this task is an analogy that denotes the class concept. With the purpose of comforting students and freeing them from fear of the syntax of a real programming language, defining a class called robot is enabled through an instrument entitled Class Definer Machine. Following the robot class definition, students will be instructed to generate an instance of the class by inputting the created chip into one of the three robot options available. When students select a robot to insert their chip into, a pop-up window, as an analogy for constructors in OOP, will be displayed. The students generate a robot by designating name, speed, and the transportation capacity of their robot. Since graphical representations of abstract concepts of OOP play an important role in novice programmers' learning of OOP (Abbasi et al., 2021), the visualization of abstract concepts of OOP are represented as an animation after the students' robot specifications. In the animated representation, the chip moves into the robot and vitalize it. Hence, as the chip demonstrates an abstract concept, class, the vitalized robot represents a particular instance of the class, an object in OOP. Our current work focused on integrating and validating more components of activity theory into this exploratory serious game.

Balancing Cognitive Load in Exploratory Serious Games

Recent research on digital game based settings showed that the settings without full components of interactive learning environment, such as interactive screen instruments, may create only a temporary and short burst of student interest (Sun, Guo, & Hu, 2021). Also, those environments should provide rich feedback facilities in order to correct students' possible errors and misconceptions (Abbasi et al., 2021). Furthermore, in many serious games for complex learning units, cognitive load is not taken into consideration sufficiently. Cognitive load, referring to the resources used by the working memory in a particular period of time, is a multidimensional construct influencing a learner in carrying out a task (Paas & Van Merrienboer, 1994). It has three different types, namely intrinsic, extrinsic and germane. For effective learning, it is necessary to have the total load of these three types of cognitive load less than the capacity of working memory (Paas, Renkl & Sweller, 2003; Paas, Tuovinen, Tabbers & Van Germen, 2003). Whilst structural configuration of learning unit is directly linked to the intrinsic cognitive load, instructional design of the content in exploratory serious games is related to the extrinsic cognitive load. Also, construction and organization of mental structures is related to the germane cognitive load.

Exploration based approaches to computer based learning, including serious games, may impose a higher cognitive load on a learner: For example, when a student explores a set of relationships between a few variables in a game environment, and tries to form an equation for the relationship, intrinsic load should be considered and balanced. Experience with game mechanics and domain knowledge in the application should be taken into account when knowledge patterns to be explored. Regardless of the level of constraints in the setting, it is obvious that there is enough material which may possibly increase cognitive load, hence a careful design and display of components, and interaction are needed.

Learning Supports in Exploratory Serious Games

An exploratory serious game as an interactive learning environment, in nature, accommodates a significant number of game mechanics and learning mechanics, that makes a serious game a complex setting where learners need intensive support either from the game itself, teachers or peers (Akkaya & Akpınar, 2022; Wouters & Van Oostendorp, 2013; Zhonggen, 2019). The learning mechanics of a serious game or any other digital instructional game presents a set of tools to support learning, however, when we consider learning support, we refer to the learning support provided separately from the learning mechanics. That is to say that learning supports to be provided to students, along with learning mechanics, will help students to actively involve cognitive processes triggered by the exploratory game in order to select new information, to organize new information and to integrate new information with existing mental schemas. Studies showed that learning supports in serious games have a significant effect on learning (Cohen's *d*=0,34) and on skill acquisition (*d*=0,62), whilst their general effect size is 0,44 (Wouters & Van Oostendorp, 2013).

Different types of learning support in serious games to teach a domain help different cognitive processes. For example, Fiorella and Mayer (2012) conducted two research studies: In the first experiment, two group of students studied electrical circuits in a serious game, while a group studied the lesson only with the game; another group, additionally, used a paper-based metacognitive explanations reflecting principles and critical features of the content as learning supports; the group receiving paper-based metacognitive learning supports had better transfer scores (*d*=0,77) than the other group. In the second experiment, paper-based metacognitive explanations as learning support was changed in a way that explanations did not directly present principles of the subject matter, but the paper-based activity required students to fill-in incompletely given principles of the subject matter; Then, while a group studies the content with a serious game, the other used the game with the second version of paper-based supports. Similar to the results of the first experiment, the group receiving paper-based metacognitive learning supports had better transfer scores (*d*=0,53) than the other group. The study reveals that serious games with learning supports in the form of paper-based metacognitive explanations pointing the principles and critical features of the content have a significant effect on learning.

In a different study (Adams, Mayer, MacNamara, Koenig, & Wainess, 2012), detailed explanations as learning support in an exploratory serious game were examined: A student group studied pathogens in an exploratory serious game, while a second group studied it in a digital presentation. Students who studied the content with a digital presentation had significantly higher recall (*d*=1,37) and transfer (*d*=0,57) test scores than the ones used the game. In the second experiment, while a group of students studied electricity unit in a serious game with detailed explanations as learning support, a second group studied it in a digital presentation: The second group had significantly higher post-test scores (*d*=0,31) than the ones used the game. The study suggests that serious games should provide sufficient guidance as learning supports, however detailed explanations should be avoided in learning supports.

Pre-training and post-training are two other modes of learning supports. Mayer, Mathias and Wetzell (2002) compared the effects of these two modes of learning supports on three groups of students' recall and transfer scores: The first group studied a multimedia lesson, and the second and third groups studied the same lesson with either pre-training or post-training. All three groups had identical recall scores, however the group who studied with pre-training type of learning support had higher transfer score than the two other groups. In a similar study, Parong and Mayer (2018) conducted two experiments. In the first experiment, achievements of students learning biology either with a virtual reality application or a digital presentation: Achievement of the students studied with a digital presentation was higher than other students' achievement. In the second experiment, achievements of students learning biology either within a digital presentation or a virtual reality application with a student summary activity following each screen were examined. Achievement of the students who used summary strategies right after interacting with a screen of a virtual reality application was higher. These studies highlight effects of pre-training and post-training as learning supports in learning environments without game features. Since students may neglect or even avoid the curricular content in an exploratory serious game, pre-training and post-training as learning supports in serious game settings are more critical than other learning settings.

In a recent study (Bainbridge et al., 2022), physics animations and short explanations as learning supports were integrated into a serious game teaching physics: Seventh and eleventh grade students who studied the serious game with added learning supports had higher transfer scores (*d*=0,36) than their counterparts who studied only the serious game. The study also reported that integrating physics animations and short explanations as learning supports to the serious game did not diminish entertaining features of the game.

The findings about effects of different types of learning supports on learning show variation, but nevertheless, along with some other studies in the literature, aforementioned studies demonstrate that learning supports can create difference in interactive learning environments, particularly exploratory serious games. Students may not sufficiently benefit and learn in exploratory and experiential serious games because (i) students may fail to relate new information with the existing mental schema, or incorrectly relate the two, (ii) students may focus on entertaining features and miss critical information in the lesson, (iii) students may need confirmation of a teacher or a knowledgeable peer in relating new information to the existing mental schema, (iv) students may experience cognitive overload in selecting, organizing or integrating information patterns. For these reasons, Westera (2019) suggests that even if students' game play is intervened and disturbed; learning supports must be presented in order to (i) explain new or complex concepts difficult to learn in a game, and (ii) provide reflective information on what a particular activity aims to teach. Furthermore, some other types of learning support may be the followings in exploratory serious games:

(a) Explaining and reminding necessary prior knowledge to learn the new content,
(b) Give students tasks of note taking about what they experience to observe their own learning progress,
(c) Direct students in each task to guide knowledge discovery,
(d) Give students tasks of note taking about what they learned as new knowledge patterns after students complete a certain number of tasks,
(e) Provide students with a prompt about what they learned after students complete a certain number of tasks,
(f) Present pre-training or explanations about abstract or complex patterns just before their relevant exploratory tasks are studied.

Order of timing of presentation of different learning supports in exploratory serious games may be categorized as before, during and after interacting with the games: Learning supports provided:

1. Just before presentation of an exploratory serious game.
2. During students' interaction with an exploratory serious game.

2.1 Just before presentation of each learning activity or each set of learning activities,
2.2 Right after studying each learning activity or each set of learning activities.

3. Right after studying an exploratory serious game.

Depending on the analysis of learning content, learning environment with embedded gaming facilities, learners and pattern of interactions within a proposed learning environment, instructional designers may determine about timing of learning supports. The nature of the contents and students' possible misconceptions in prerequisite learning contents as well as learning difficulties observed should be considered when adding learning supports to serious games.

Discussion

Research suggests that the arousal and reward mechanisms associated with games, mediated by the endocrine system, play a significant role in attracting students and making these activities more engaging compared to traditional curricular tasks. The immediate gratification and sense of accomplishment provided by games can be more appealing than the delayed rewards of academic work. Moreover, multiplayer games that involve collaboration with others can trigger the release of oxytocin, enhancing the social aspect and further reinforcing engagement.

Theoretical issues raised by research literature on serious game design are very rich in their use of learning theories (Bainbridge et al, 2021; Clarke, 2020; Rooney, 2012). However, many of the applications cited, even in scholarly reports, were not based on a sound learning theory and/or limited to practicing particular knowledge and skills. Furthermore, it is hard to find an instructional design model in some of those applications. The school curriculum does not have only simple learning units, but also includes complex and abstract learning units; students' failure, boredom and dropout in complex units are high (Abbasi et al, 2021), for that reason studies should enlighten development of serious games design for particularly complex units. Our endeavor in forming a blended design model is based on four pillars: (1) the 4C/ID instructional design model to easily handle conceptual as well as procedural knowledge by the help of intensive learning supports, (2) ARCS theory and experiential learning model to author motivating and engaging activity sets for even low level students to explore in subjects involving complexity, (3) Flow model to keep students on tasks, and (4) Activity theory to look into the design of learning environment from a broad perspective to consider socio-contextual and cultural issues including classroom/e-classroom dynamics.

Our arguments pointed out several shortcomings that may contribute to the preference for games over curricular activities. These include the indirect and limited nature of user interaction in virtual worlds. Research (e.g., Garris et al., 2002; Greipl et al., 2021) suggests that students' playful activities and curricular task handling should be integrated into the virtual environment to create a more immersive and engaging experience. Such integration of game and learning mechanics in serious games should address cognitive load and reflection skills in instructional design. However, various frameworks and models used in serious game design had their limitations, such as being too domain-specific, oversimplifying complexity of learning, neglecting contribution of cultural context to learning, and prioritizing entertainment over learning. We emphasized the need for frameworks that incorporate sound instructional design principles, pay particular attention to flow of learning activities developed by considering motivational factors in details. Furthermore, the studies (e.g., Miettinen, 2000) highlight the importance of ELEs as settings that promote active engagement, reflection, and discovery of conceptual as well as procedural knowledge. ELEs provide opportunities for students to experiment, make mistakes, and develop knowledge elaboration skills. They encourage students to actively construct their understanding through learner-driven inquiry and engagement with multiple representations of information. We argued that to increase the effectiveness of ELEs different learning support mechanisms are key, and therefore, must be added to gamely learning environments.

Developing a successful exploratory serious game involves more than just generating an immersive environment and including curricular content. It necessitates thorough consideration and careful planning throughout the design and production process to align the media with the relevant content, seamlessly integrate curricular content into gameplay, and facilitate learning through well-designed feedback and clues. Moreover, supplementary resources should be developed to enhance the complex process of learning with the game (Bainbridge et al., 2021); Students' primary objectives in a serious game may not be engagement with the activities conveying curricular content but engagement with the game mechanics. The learning activities and design elements with support information should be arranged in a way that even students with game objectives complete all learning activities, and those students must be convinced to put learning objectives to the front.

Conclusions and Implications for Further Work

Instructional design of an environment is a multifaceted task with many challenging issues: For example, finding or creating an intriguing and enjoyable story with meaningful and consistent events whose objects, operators and interactions precisely represent knowledge and skills of a learning unit is a laborious task. Instructional designers should cooperate with educational researchers and teachers in order to (i) design students' interaction with events of the story through task handling in an exploratory manner, (ii) find ways of organizing learning activities, to be completed individually or collaboratively, which help students to overcome complexities of knowledge patterns and to avoid misconception development. To enlighten an exploration process in learning, along with others, there are two very essential issue in exploratory learning game settings: One of them is curricular task systems. The second is that density, characteristics (whether used for selection, integration or organization of knowledge) and timing (before, during and after the game activity) of supportive information. Hence, instructional designers of exploratory serious games should keep in mind the research findings that "unguided open-ended exploration might result in fruitless floundering, and therefore be significantly less effective than direct instruction" (e.g., Kirschner, Sweller, & Clark, 2006).

The overall arguments presented above have some implications for both serious game developers and serious game researchers. Serious game designers should consider the followings: (a) Objectives of each learning support either content related or game-usage pattern related must be separately treated first, and the question of whether the designed support eases learning or eases game play should be answered. (b) When game elements, learning content elements and instructional elements are combined for a particular task scheme, the type and depth of cognitive load students may experience should be critically analyzed to avoid overload. (c) Only well-designed learning supports backed by instructional justification should be incorporated to serious games. Students may over focus on play and miss the curricular content embedded in the game, instructional strategies with learning supports should be customized to get students' attention and to overcome students' learning difficulties (d) When selecting a contextual nest for the game, particular attention should be paid to large number of events the context can handle, and allow seamlessly embedding variety of screen objects and operators which will convey domain knowledge. (e) Game designers should provide robust assessment mechanisms and meaningful feedback, and explicitly direct learners to track their progress and identify areas for improvement.

Scholars in the field of exploratory serious game should conduct validation studies to find out the best balance among game elements, learning content elements and instructional elements which are combined for a particular task scheme. Learning supports and game-related supports may interact with each other, investigations should be conducted to measure how such interactions affect students' engagement and learning in a game. Such studies should consider each element of supports as independent variables in game settings, and setup comparative experiments. As part of an instructional design, in evaluation of exploratory serious games, particular effects of varied types of supportive information bearing in mind density, nature and timing on diverse learning outcomes, and in-game performance, must be examined. Additionally, such evaluation studies should investigate interactions between the varieties of supportive information (internal, external and distributed scaffolds) provided by pedagogical agents, students' teacher, students' peers and/or the game help menu. These investigations will clarify roles of interacting components of supportive information in maximizing students' cognitive engagement in selection, organization and integration of new information in the learning content at hand. Future research should investigate the role of challenge levels of tasks and flow in learning with the help of different instructional supports including the supports a human teacher may provide. Moreover, roles of collaborating students in a serious game are critical, and need examinations. Finally, moderating and mediating variables possibly influencing the dynamics of learning mechanics, game mechanics and contextual instruments of a serious game are also critical topics of investigation.

Contribution Rate of the Researchers

The first author contributed to Conceptualization, Investigation, Literature Review, Supervision, Writing - Original Draft. The second author contributed to Conceptualization, Visualization, Review & Editing. The third author contributed to Conceptualization, Validation, Review & Editing.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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