An overview of digital game-based learning development and evaluation models

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Abstract - **From an educational point of view, the design of digital games, especially the so-called serious games, is a powerful tool that can improve engagement and motivation, help students develop digital literacy skills, and deepen their understanding of the domain, which could eventually have a positive impact on the overall learning process. For this reason, game development is increasingly being incorporated into the learning process and more and more educators are using this strategy to improve the quality of their teaching. Given the inherent multidisciplinarity and complexity of such projects, the design of game design-based learning activities, as well as their assessment, is not an easy task. As a result, many approaches have been developed, some of which rely on existing, proven models such as Bloom's Taxonomy, while others incorporate the principles of project-based learning or motivational design processes. This study provides an overview of the different approaches to the design and assessment of game-based learning systems and activities, outlining their main features and characteristics.**

Keywords – game-based learning; project-based learning; learning models.

I. Introduction

As technology increasingly enters the classroom changing the current educational landscape, the scientific field of educational digital games is gaining in popularity and importance. Educational games are described as games created with the main purpose of enhancing the educational processes. The enhancement is usually achieved with improved engagement, motivation, and interest in learning [1], which, in turn, are results of playfulness, collaboration [2], elements of challenge, competition, and immersion [3], which can be found in different digital games. Furthermore, it is believed that besides boosting interest and motivation, making the learning more enjoyable activity, educational games could also improve students' attitudes toward in-class participation and the learning process itself [4], which could have a long-term positive impact on the entire student education path.

To take advantage of the benefits offered by educational games, teachers are increasingly incorporating them into their lessons, and game developers and researchers are creating more and more games, combining the various principles, approaches, and theories of educational game development that have evolved in recent years.

As the diversity of the field increases, the design of a successful educational game, as well as the evaluation of existing solutions, becomes an increasingly difficult task. In recent years, several patterns have emerged, based on which most authors approach this problem. Some developers follow ideas from Bloom's taxonomy, adapting individual elements to fit the principles of game-based learning [5]. Others opt for a project-based approach, where students actively participate in a Design-based learning process of game creation, instead of simply playing the game [6], while some researchers put focus on the alignment of learning outcomes and objectives with the learning process, through the Constructive Alignment teaching framework [7].

This study provides an overview of different approaches with case-studies for design and evaluation of learning systems and activities based on computer game development outlining their key features and characteristics. The existing methodologies in this area were identified through a detailed and methodological search of three popular bibliographic databases: Science Direct, Scopus, and Google scholar.

The motivation for this review is found in research activities on the project Digital Literacy Development Network "Digitalna.hr" which aims to provide novel guidelines, based on existing best practices, for inclusion of game-based learning of a broad spectrum of digital competencies at primary school level. Such competencies are aligned with STEAM and include, per example, logical thinking, independent and collaborative learning, problem solving, literary skills and storytelling, teamwork and competitiveness, computer programming, video and audio content design, multimedia production, etc. The combined guidelines will be presented at both national and local levels to be included in informal or formal curricula.

The remainder of this paper is organized as follows: Section 2 gives a short overview of the existing game-based learning methodologies. Section 3 describes in-depth five identified prominent game-based learning development and evaluation models and explains how they were selected for this overview. Case studies of described models are included and cited. Finally, Conclusion discusses which of the presented models are best suited for inclusion in the game-based learning activities at primary school level and provides an outlook into the future work regarding development of school curriculum guidelines for game-based learning in acquisition of digital competencies.

II. GAME-BASED LEARNING METHODOLOGY IN EDUCATION

With the emergence and popularization of computers and the Internet in schools, several new learning methodologies emerged. They all involve the use of some sort of technology but distinguish the ways in which educational goals are achieved, as well as the focus of the approach itself. The use of games, which are mostly digital in this context, has crystallized two basic directions, game-based learning [8] and gamification [9]. While gamification is usually described as "the use of game elements in a context that is not itself a game" [10], but still achieves some of the desirable outcomes of digital games as increased motivation and engagement [11] [12] [13] [14], game-based learning puts more focus on gameplay, story and immersion, so it could be described as "a type of game with defined learning outcomes" [8].

Roughly, different models, frameworks, and approaches could be divided into two main groups, depending on their starting point-of-view, i.e. what was the greatest emphasis on during the design and development of the game-based learning activity. These are pedagogical or educational approach, and game design approach.

The pedagogical approach emphasizes presentation and order of given learning material, the amount of resources presented to the student, and typically pays more attention on a learning outcomes. The foundation of these models lies on other pedagogical models, for example on the Bloom's framework for categorization of educational goals [5], ARCS model of motivational design with four key elements in the learning process [15], or the Instructional Design model [16] and Constructive Alignment [7].

On the other hand, the game design approach puts more focus on typical game elements as storytelling, immersion, or game progress, but still considering the pedagogical aspects of the final game. The example of this approach is the so-called Game Design Matrix [17], based on the MDA (Mechanics, Dynamics, and Aesthetics) game design framework [18], the framework which adapts game interaction cycle to fit the needs of young learners [19], or the model which puts the learner in the position of game creator, by adapting the DBL (Design-based learning) process to the game theme [6].

III. MODELS FOR EVALUATION OF LEARNING BASED ON GAME DESIGN

The presented models were selected based on being the most frequently used models for evaluation of learning through game-design in the corpus of science papers published in the last 5 years from the areas of education, game-based learning, game design and game jam within groupwork or classwork activities. This corpus was constructed and annotated by the authors after an exhaustive search of Science Direct, Scopus, and Google scholar bibliographical databases. In this process 128 science papers were retrieved and ranked by their citation count. From this a subset of 50 papers with 20 or more citations were analyzed. The tag cloud of this subset built from keywords in the papers' titles and abstracts is in Figure 1.

Figure 1. Tag cloud with raw keywords from science papers using game learning models analyzed in this overview.

A. *Revised Bloom model in the mobile setting*

Learning with mobile devices promotes self-management and self-confidence in the learning process [5]. Mobile devices provide the opportunity to learn during free time and, while improving social learning, to correct a misstep at the same time. Mobile learning is a great potential for the use of mobile devices in e-learning [5].

When testing objectives with respect to knowledge and cognitive processes, objectives, instructional activities and materials, and assessments are each tested with respect to Bloom's Taxonomy rather than each other. Bloom's Taxonomy allows educators to examine differences in alignment from one subject to another or from one grade level to the next.

Since the essence of mobile learning is based on collaborative learning, a mobile application based on Bloom's revised taxonomy supports collaborative learning. The pedagogical capabilities of mobile learning technologies provide the opportunity to connect learning with conversations between students and lecturers, students and peers, students and subject matter experts, or students and the social environment in any context. Finally, mobile learning is seen as a great opportunity for distance education because of its content-driven structure and its unique feature of instant learning.

Revised Bloom's Taxonomy is used to represent a particular cognitive process in learning step by step [20]:

Remember: Getting, identifying, and calling to mind relevant information by long-term memory.

Understand: Identifying, interpreting, exemplifying, classifying, summarizing, comparing, and explaining the meaning of didactic messages that contains communication forms of speaking, writing and graphical.

Apply: Using, implementing, or applying the appropriate method to a given situation.

Analyze: Dividing materials into components and then uncovering, discriminating, or organizing the relationships between each other, or between any component and the entire structure or goals.

Evaluate: Making decisions, checking, or criticizing based on the standards or criteria.

Create: Producing an original product, or creating an original, easily understood form of a whole by bringing components together.

Unlike Bloom's original taxonomy, Bloom's revised taxonomy has two dimensions: Knowledge and Cognitive Processes. It has merged the knowledge dimension (factual, conceptual, procedural, metacognitive) with the cognitive processes dimension (remember, understand, apply, analyze, evaluate, create) [21] [22] [23]. Bloom's revised taxonomy can be used to analyze the goal of a curriculum or instructional unit, to classify learning activities according to learning objectives, to become aware of the relationship between assessment and learning/teaching activities, or to examine instructional materials [24]. The authors also point out that the revised Bloom's taxonomy could be used to design mobile learning environments at the level of metacognitive knowledge (learning to learn). Learning a fact, concept, or procedure that can be implied for a goal or outcome can be measurable. The revised Bloom's taxonomy used in this study is shown in Figure 2.

The evaluation study examined the revised Bloom's taxonomy in designing mobile learning applications in terms of cognitive processes and learning outcomes for realizing effective learning. In addition, the benefits of the revised Bloom's taxonomy were evaluated in relation to issues such as analyzing the objectives of a curriculum or syllabus, classifying learning activities according to learning objectives, and recognizing the relationship between assessment and learning/teaching activities. In conclusion, the authors recommend the use of Bloom's revised taxonomy in the development of mobile apps for learning. They also point out that a variety of alternative models can be used for developing mobile apps for learning, such as the SOLO taxonomy [25], Fink's taxonomy of significant learning [26], and the model of parental involvement (PI model) [27]. In future research, it is necessary to compare different models before developing learning content for mobile apps and also open and distance learning courses.

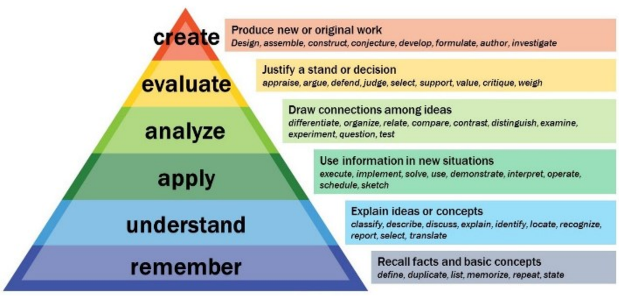

Figure 2. Revised Bloom taxonomy adapted from [21].

B. *Multiplayer Online Game-based Learning System*

The Multiplayer Online Game-based Learning System (MOGLS) enables learners to acquire knowledge about Enterprise Resource Planning for practice and exams. The MOGLS is based on the ARCS model of motivation design [15]. The MOGLS model provides learning logs, ranking logs, and feedback at the end of the test to motivate learners to learn. Unlike other models in this paper, MOGLS is primarily designed as a computer system. The theoretical background in education is predominantly based on the existing ARCS model [15].

The underlying ARCS model of motivation design emphasizes motivation, which means that students must actively participate in an activity to achieve a specific goal. Among the many proven motivation theories incorporated into the ARCS model are expectancy-value, achievement motivation, and social learning. The ARCS model focuses primarily on strengthening systematic instructional design and designing materials that encourage student participation. Four factors in the ARCS model that explain motivation are: 1) attention, 2) relevance, 3) confidence, and 4) satisfaction. Student motivation must be consistent with these four factors to increase motivation to learn [28]. The schema of the ARCS model of motivation design is shown in Figure 3.

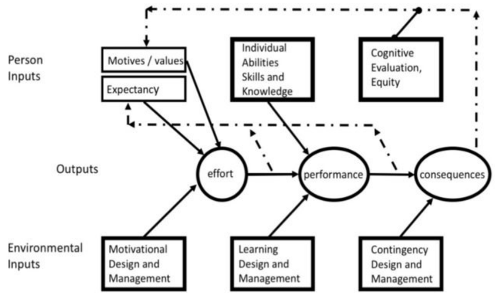

Figure 3. Attention, Relevance, Confidence, and Satisfaction (ARCS) model of motivation, adapted from [28].

Another tool employed in this study for evaluation of the learning success was a taxonomy and interactive model from DeLone and McLean for conceptualizing success of an information system in education, the so-called D&M IS Success model [29]. This taxonomy identifies six variables for IS success: system quality, information quality, usage, user satisfaction, individual impact, and organizational impact [30]. Later in 2003, a revised model was proposed. An important addition in the updated model was the inclusion of service quality as an additional aspect of information system success. Schema of the updated D&M IS Success model is shown in Figure 4.

The MOGLS system allows students to be tested through the variability testing module, which increases students' motivation to learn and curiosity. When students know that the learning system is related to ERP courses and take mock tests, they are more familiar with enterprise resource planning knowledge. Students then use various tests, understand their learning circumstances, and then build their confidence. Eventually, students who participate in various tests and challenges are able to achieve more and more learning objectives, building their confidence.

In the validation study conducted, the MOGLS system was shown to increase the completion rate of students taking the Enterprise Resource Planning certification exam, improve students' intrinsic motivation to actively learn, and increase their learning performance [15].

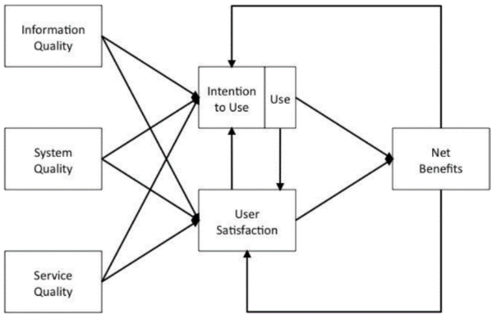

Figure 4. Updated D&M IS Success Model for conceptualizing success of an information system in education, adapted from [28].

C. Constructive alignment model in teaching Digital Game Based Learning

Constructive Alignment (CA) is an outcome-based teaching and assessment framework for designing learning activities. CA aims to develop an outcome-based approach to learning activity design that aligns learner engagement through the activity with learning goals and outcomes. Therefore, CA focuses on proposing constructively aligned learning experiences where assessment is the result of specifically selected training activities proposed based on intended learning outcomes [31]. A conceptual schema of the CA framework is illustrated in Figure 5.

For CA to be successful, the learning content and method must be clearly defined before teaching takes place [32]. Design activities are then proposed to actively engage students and help them achieve the previously defined outcomes.

The CA teaching framework is based on two main aspects: the constructive aspect and the alignment aspect [31]. The first aspect aims to engage students in building their knowledge through learning and teaching activities specifically proposed for the context of specific learning outcomes. The second aspect describes the actions taken by teachers to help learners achieve the defined learning outcomes through appropriate learning activities.

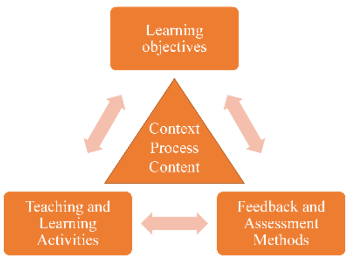

Figure 5. Conceptual schema of the Constructive Alignment (CA) teaching and assessment framework.

Moreover, according to [33], CA consists of four main steps: (1) defining the intended learning outcomes, (2) selecting teaching/learning activities that lead to the achievement of these intended learning outcomes, (3) assessing the actual student learning outcomes to see how well they match the expected outcomes, (4) achieving a final grade.

The CA's structure is also based on the idea that students place the most value on the final assessment [33]. The result of this approach is that assessment becomes the curriculum for students as they focus on passing the exams: They focus on what they believe will be tested. CA emphasizes the importance of students' intended learning outcomes to design learning activities that learners can effectively develop.

The activities on CA can be categorized as self-directed, peer-directed, and teacher-directed [32]. The design of the course assessment tasks must be aligned with the intended learning outcomes. This means that students must achieve the intended learning outcomes in the way they were formulated in order to complete the assessment tasks.

Another benefit of CA is that it can reduce students' cognitive load when participating in learning activities. Since mismatched curricula and activities can distract and overwhelm students participating in learning activities, appropriately designed activities that are also constructively aligned could help students focus on meaningful learning tasks related to the stated intended learning outcomes. This argument becomes even more important when considering the cognitive abilities of students and software users [34].

The application of CA in teaching Digital Game Based Learning (DGBL) at HE could have a positive impact by both improving the quality of the courses offered and helping instructors evaluate their courses based on clearly defined intended learning outcomes [7]. While the field of DGBL appears to be engaging and motivating for students, the lack of connections between assessment tasks and DGBL-related training and learning activities can lead to superficial or incomplete interaction between students and the games [35]. The necessary alignment between Learning Mechanics and Game Mechanics to reduce students' cognitive load and facilitate their learning experience through play is shown in Figure 6.

Figure 6. Constructive Alignment (CA) in Digital Game Based Learning (DGBL). Adapted from [35].

D. Game Design Matrix

The Game Design Matrix (GDM) is a framework that uses the Mechanics, Dynamics, and Aesthetics (MDA) design process as the cornerstone of a step-by-step design matrix aimed at new game designers [17]. It allows someone with a minimal background in game design to achieve a much higher level of effectiveness. This is achieved by using learning objectives and environment constraints to map ideal game dynamics and mechanics.

The rationale behind the GDM concept is that all games, at their most basic level, can generally be categorized as a combination of the interactions of mechanics and dynamics components in the MDA process, and thus these that are most appropriate components for any game designed to achieve a particular goal. In doing so, the building blocks of MDA for serious game development are realigned so that the dynamics of a game are selected first to focus on the primary driver of the learning outcome [36].

Based on environmental constraints and learning objectives, an optimal set of game mechanics and game dynamics for a given design is identified, isolated, and mapped. Game components and esthetics are developed based on the mechanics and dynamics selected using GDM.

The GDM process consists of four steps: 1) Identify Learning Objectives and Subject Matter, 2) Identify Environmental Constraints, 3) Isolate Game Dynamics and 4) Select Game Mechanics [36]. The GDM steps and their mutual dependencies are shown in Figure 7.

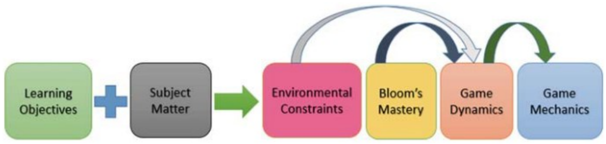

Figure 7. Game design matrix (GDM) structure adapted from [36].

The last step is the core of the GDM process, where the choice of game mechanics enables the intended game dynamics. Often it is only necessary to use one or two mechanics to create a dynamic, and it is equally important to group similar dynamics using the same mechanics to keep the complexity of the game manageable.

E. Design-based learning model

Design-based learning (DBL) was developed as a means to improve computational thinking (CT) [6]. In this respect CT was defined as society-based technologies coexisting in digital and analog forms and as a cognitive ability to communicate one's thoughts or to solve problems using digital materials [37]. CT was first presented in the Creative Computing Guidebook developed by the Media Laboratory of the Massachusetts Institute of Technology [6]. The researchers asserted that CT is useful for making meaningful products because it allows learners to relate their innate creativity, imagination, and interests to the principles of computer science [37]. In particular, most young learners use computers as passive consumers and users, not as creators or designers. Creative computing helps learners transform themselves from being mere consumers of computers to individuals who use computers to create content and to produce interactive media materials.

The ability of DBL to form CT was verified in two independent studies that targeted average elementary school students in a wider range of grades in order for the results to be generalizable and gifted, fourth-grade elementary students [6]. Both studies involved creating a computing environment designed to elicit students' innate and original ideas for creating a project. During the design of the verification experiments it was noted that CT education is different from general programming education, which is necessary for average students because the education is to enhance thinking skills [37]. Both studies analyzed computational problem-solving ability, self-interest, self-CT, awareness about the computers, and preference for steps of DBL. To determine the homogeneity of the student groups in the studies, previous experiences of programming were tested, and additionally self-efficacy were examined.

The DBL process has four steps [37]:

1. Design: This is the process of creating and interacting, rather than simply using. This includes giving shape to an idea through creative design engineering and problem-solving before advancing to a new project.
2. Personalization: This is the process of creating meaningful and personally relevant content. This includes developing prototypes of the new materials.
3. Collaboration: This process includes creating new materials together with other people and adding various ideas to the generated content.
4. Reflection: This is the process of reviewing and thinking about the creative materials. This process includes evaluating and revising them.

The four steps of the DBL process are illustrated in a simple abstract schema in Figure 8.

Figure 8. The four steps of the DBL process.

Reported results of validation studies indicate: 1) DBL enhanced students' self-efficacy and self-interest, 2) DBL is a more effective way of improving students' CT ability than is the traditional method of teaching, 3) by employing DBL students became more aware of computers than through traditional teaching methods, 4) DBL helps students in the design and collaborative activities, and 5) DBL has improves self-interest, CT ability, and awareness of computers not only on gifted students but also average students [37].

IV. CONCLUSION AND FUTURE WORK

As personal and mobile computers and computer games become more ubiquitous, the importance of digital game-based learning increases. The process of developing a successful educational game, as well as evaluating existing solutions, is also becoming an increasingly difficult task. However, several patterns have emerged by which most authors approach this problem.

In this paper, five different models for developing and evaluating digital games for teaching digital literacy are presented and explained. A thorough literature review was conducted to identify the most commonly used and the most promising recent models for further work on developing digital learning guidelines for elementary schools.

The presented models are mutually diverse. They were compared based on their ability to assess key aspects of successful learning in a classroom curriculum: enthusiasm and motivation for learning, determination to achieve high standards of performance, independent and group learning, and linking and applying learning to new situations. In this regard, it is necessary to conduct a classroom experiment to evaluate the usefulness of all the models presented and rank them accordingly. However, from the aspect of practicality and experience from case studies in the published literature [38], the ARCS model and the MOGLS as its derivative are the most promising models for determining learning success in game development. However, depending on the application situation, another model may be optimal.

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