Advances in Game-Based Learning

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Interdisciplinary Design of Game-based Learning Platforms

A Phenomenological Examination of the Integrative Design of Game, Learning, and Assessment

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Chapter 1
Introduction and Prior Research Review

Abstract Games are not just a vehicle to enhance learning but a new way of understanding and organizing learning. The starting point of an optimal integration of learning and play in the game setting is to identify the salient elements of learning itself and the inherent learning processes in gameplay. In this introductory chapter, we discuss relevant theoretical perspectives on the nature of knowledge and learning that guide the exploration of playful elements in learning and consequently the opportunities for learning that games offer. We then provide a conceptual review of prior research of game design and discuss the challenges and the interdisciplinary nature of educational game development. In the end, we introduce the overall goal, structure, and chapters of this book.

1.1 Games for Learning

The best way to motivate students to embrace learning is to "make it fun", and hence making learning fun seems the most well-known claim on the educational power of games (Kim, Song, Lockee, & Burton, 2018). Games are structured or organized play, requiring the player to follow a specific set of rules to tackle obstacles and attain a goal (Klopfer, Osterweil, & Salen, 2009; Suits, 1978). Although games are typically considered as a high-quality multisensory rendering environment, the main reasons for the interest in game for learning are not the medium's success but the motivation of players and their deep engagement while playing (Denis & Jouvelot, 2005).

While learning and play are often associated with opposite connotations (Mitgutsch, 2009), learning and play share a key attribute: Both are challenging, time-intensive, and interactive processes that require cognitive effort and willingness to acquire new knowledge or skills. Yet people tend to avoid and dislike challenging learning experiences in the educational setting while engaging in and enjoying gameplay as a form of *hard fun*. This observation, along with the interest in creating intrinsically motivating learning, has triggered the examination of games as a promising tool and environment for learning. Particularly, prior

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research has focused on defining the nature and circumstances of “pleasantly frustrating” learning experiences and how these are and can be aligned with the gaming experience (e.g., Gee, 2003; Rieber, 1996). Some scholars have also examined the phenomena of game engagement from both intrinsic motivation and well-internalized extrinsic motivation perspectives (e.g., Csikszentmihalyi, 1997; Deci & Ryan, 1985; Malone & Lepper, 1987).

The idea of using games for learning purposes was discussed early by Clark C. Abt in 1975 and further formulated by other scholars of serious games (e.g., Breuer & Bente, 2010; Charsky, 2010; Sawyer, 2003; Susi, Johannesson, & Backlund, 2007). The educational purpose can be assigned to a game in the design, or by the context used. Games designed primarily for entertainment, like commercial off-the-shelf (COTS) games, can be used in a teaching and learning context, though its learning effect is an exogenous one.

Despite the innate connection between gameplay and learning, not all forms of games are equally suitable for learning purposes; simply adding educational material to an enjoyable game or presenting it in a game-like setting will not create an engaging and effective game for learning purposes (Breuer & Bente, 2010; Ke, 2016). A frequent cause of a segmentation between play and learning in a game is that win criteria for a game do not necessarily equate with the things players are supposed to learn through playing the game (Van Staalduinen & de Freitas, 2011). Specifically, there are variant categories of learning in games, including things that we can learn and are deliberately designed in a game (or intentional learning), things that we can learn but not necessarily designed into the game (or collateral learning), and things that we must learn in a game to successfully finish the game (Becker, 2008). The desirable situation is that the first two categories overlap with the third one, in that both intended and incidental learning are enabled and assured by gameplay. The starting point of an optimal integration of play and learning in the game setting should be to identify the potential enjoyment (or the playful elements) of learning itself and the inherent learning processes in gameplay (Rodriguez, 2006). Hence, games are not just a vehicle to enhance learning but “a new way of understanding and organizing learning” (Breuer & Bente, 2010, p. 14).

In this introductory chapter, we describe relevant theoretical perspectives on the nature of knowledge and learning that help us to explore playful elements in learning and consequently the opportunities for learning that games offer. We then provide a review of prior research of game design and discuss the challenges and the interdisciplinary nature of educational game development. We introduce the overall goal, structure, and chapters of this book at the end.

1.2 Nature of Knowledge and Learning Pertinent to Games

Dewey defined knowledge as “not information, but a mode of intelligent practice and habitual disposition of mind” (1910, p. 124). This definition highlights two salient elements of knowledge that are apt to frame the design of game-based learning: a practice that crafts and enacts intelligence and intelligent habits or ways of thinking constituted in the practice. The intelligent practice, called reflective inquiry by Dewey, comprises mainly the processes of identifying a problem (i.e., a quandary that needs to be resolved), studying the problem through active engagement, and reaching cognitive conclusions as the problem is resolved. The central facet is the *method* by which a cognitive conclusion is reached; hence, the process/action of identifying, actively studying, and resolving a problem, more than the cognitive conclusion itself, is the item of value (Dewey, 1929; Hiebert et al., 1996). During the action of inquiry or problem-solving, *scientific attitude*—"willingness to endure a condition of mental unrest and disturbance" or that is capable of enjoying the doubtful—should be deliberately constructed and is alone worthy of the title of knowledge (Dewey, 1910, p. 13). In view of that, perfecting the method of inquiry and constructing scientific attitude are more significant to realize the meaning of knowledge than that of acquiring and utilizing information and technical procedures.

Derived from Dewey's perspective is the argument for *problematizing* subject matter knowledge (Hiebert et al., 1996). "Allowing the subject to be problematic means allowing students to wonder why things are, to inquire, to search for solutions, and to resolve incongruities" (Hiebert et al., 1996, p. 12). The conventional conception of problem-solving typically focuses on the *application of acquired knowledge* in realistic situations, whereas problematizing a topic emphasizes *knowledge acquisition*. Problematizing mathematics, for example, involves treating experiences as problems, examining or manipulating them via *overt doing*, and consequently constructing *structural understanding* that includes insights into the structure of mathematical objects, strategies for solving problems (both procedures used for particular problems and general ways of thought needed to construct the procedures), and dispositions toward mathematics (e.g., seeing mathematics as an intellectual activity in which they can participate). Notably, real-life problems provide a legitimate context for problematizing mathematics, though it is only one context for it. The value of a real-life problem depends on whether students problematize the situation and whether it offers the chance for students to acquire structural understanding after problem solving. In other words, the knowledge to be acquired depends as much on the mathematical ideas embedded in the task (e.g., a game-based inquiry) as on the way it is packaged. Therefore, the focus of the design research of learning in games is not only on what subject content or information is integrated but *how core game tasks will legitimize subject-problematizing actions to generate structural understanding*.

In alignment with the aforementioned learning perspectives is the proposition to establish the learning activity or task as an *epistemic practice* (Eriksson & Lindberg, 2016). With a similar assumption that knowledge is constituted in people's actions, an epistemic learning practice is characterized by open and question-generating objects (or tasks) with which learners work. Apart from contextualizing a learning task in relation to students' everyday interests, it is important to choose and shape a task so that the students discern that the previous tools and solutions they are familiar with are restricted. When working with the learning task, students get to test previously developed methods and tools and (re)develop theoretical generalizations that are characteristic for a specific subject. In other words, the learning task should be developed to enhance such kinds of theoretical thinking, by requiring that "core principles" or "conceptual relations" constituting a specific knowing are discerned and understood through learning actions in a content-rich epistemic practice.

In summary, the above theoretical underpinnings for learning in games suggest that the acquisition of discipline-specific, structural understanding (or theoretical thinking), compared with the application or acquisition of static content or information, is more crucial for the goal of the learning-play integration. Subsequently, designing gameplay as an epistemic learning practice that delineates subject-problematizing actions is a fundamental means to establishing game-based learning. Educational game design is to create meaningful, interactive, and challenging experiences involving the user as the conductor of his own intellectual practice and development.

1.3 Designing Games for Learning

1.3.1 Research of Game Design

The content of a game is its behavior, not the media that streams out of it toward the player (Hunicke, LeBlanc, & Zubek, 2004). The difference between games and other design artifacts is that their consumption (by players) is relatively unpredictable, because the interaction between players and the coded game subsystems creates dynamic and often unpredictable behaviors (Hunicke et al., 2004). Gameplay is hence defined as the structures of player interaction with the game system and interaction with other players (Björk & Holopainen, 2005).

Although game design is a frequent theme of textbooks and articles, a unified design theory diagnosing and predicting the structural relations between desirable gameplay and game subsystems is still lacking. The *mechanics, dynamics, and aesthetics* (MDA) framework by Hunicke et al. (2004) is an earlier effort contributing to this aim and describes three sectors of a game system. Mechanics are various actions, behaviors, and control mechanisms afforded to the player within a game context. Dynamics refers to the run-time behavior of the mechanics acting on player inputs over time or gameplay. Aesthetic represents the desirable emotional responses or experiences evoked in the player. From the designer's perspective, the mechanics give rise to dynamic system behavior, which in turn leads to particular aesthetic experiences. From the player's perspective, their respective player or aesthetic experiences, such as sensation, fantasy, challenge, fellowship, discovery, and expression, are brought forth by observable dynamics and, eventually, operable mechanics. Even though the MDA framework lacks instruction detailing the combination and proportion of mechanics that will result in variant aesthetic goals, it helps to describe how and why different games appeal to different players or to the same players at different times. It should be noted that in games for learning purposes, the desirable player experiences are not just emotional responses but more cognitive involvement. However, inadequate game design research addresses the mechanics and dynamics in relation to the cognitive facet of player experience.

Extending the MDA framework, Salen and Zimmerman (2005) discussed *meaningful play* as an emotional and psychological experience in a game that emerges from the relationship between player action and system outcome. Specifically, they described that meaningful play occurs when the relationships between gaming actions and their outcomes in a game are both *discernable* and *integrated* into the larger context of the game. Discernable means that the result of the game action is communicated to the player in a perceivable way. Integrated means that an action a player takes not only has immediate significance in the game but also affects the play experience at a later point in the game. In other words, game design is the process by which a designer creates an interactive and engaging system to be encountered and proactively investigated by a player, from which meaning emerges. Importantly, interactivity afforded by the coded/designed system comprises not only *functional interactivity* (or the usability of the interaction interface) but also *cognitive interactivity*—psychological, emotional, and intellectual participation between a participant and a system.

Prior research of game design tends to depict play experience as the product of coding operable mechanics and observable interactivity. But there is still a debate between ludology and narratology in the game design literature. In comparison with the argument for ludology—systems of puzzles, rules, and interactivity designed to frame play or fun (e.g., Adams & Dormans, 2012; Koster, 2013; Salen, Tekinbaş, & Zimmerman, 2004)—the narratology proposition (e.g., Jenkins, 2004) emphasizes the design of narrative structure as the anchor of play experience, describes the importance of designing *environmental storytelling* via spaces and artifacts in a game, and argues that gameplay enacts a personally meaningful story or life experience whether story is a defining game feature or not.

Recent discussions of game design (e.g., Adams, 2014; Schell, 2014) manage to coordinate the perspectives of ludology and narratology by arguing that mechanics (or interactivity) and environmental storytelling (or embedded narrative) in a game, jointly and ultimately, serve the purpose of *experience design*. Play or fun is co-framed by players' prior experiences, the designed game system, and the emergent interactivity (dynamics) between the players and the system. Even though components of the experience to be designed are well specified in the game literature, the paths toward the goal are dynamic and murky. Due to such a dynamic and participatory nature of play experience design, mostly game design is based on the intuition and experience of designers with the infield experimentation and iterative refining. Descriptive or analytical analyses of the game elements, design rationales, and experimented design strategies, however, will help to guide the experimentation. Particularly, empirical and longitudinal research on variant processes of design creation and experimentation in diverse game design projects will help us construct the collective knowledge as well as a unified while scalable theory of game design.

1.3.2 Prior Research of Educational Game Design

Multiple conceptual or design models of educational games, or game-based learning platforms, have been proposed in the literature of instructional design and learning technologies. For example, Kiili (2005) proposed an experiential gaming model that reflects the perspective that learning is a construction of cognitive structures through action or practice in the game world. The model depicts game challenges (or problems) as the center of game-based learning flow by initiating active experimentation, reflective observation, and schemata construction. Kiili's model outlines the process of experiential game-based learning with its implications for educational game development but lacks a design description of the game systems. Amory (2007) described a theoretical framework, called the game object model, for educational game research and development. The model sets game space, problem space, and social space as the three components of the educational game system and prescribes a list of defining features for each space. For example, drama, role models, interaction, and gestures are listed as the game space features; explicit knowledge, literacy, and information communication are considered design elements of the problem space, while the social space includes computer-mediated communication along with social network analysis. In general, Amory's game object model presents a visionary integration of related theoretical constructs of gaming, learning, and social community. It has not explained the actual design mechanism and lacked technical definitions of the theoretical constructs for designers. Similarly, de Freitas and Oliver (2006) used a four-dimensional framework to summarize the key analytical or evaluation constructs (i.e., learner specifics, pedagogy, representation, and context) of a virtual-world and gaming-based learning environment. These aforementioned generic models are all aimed to outline and categorize related constructs underlying the integration of gaming and learning processes. They focus on a conjectural or an interpretive analysis of the relationships and structure of these constructs as a system, from more of an educational researcher perspective. Other works, such as that of Calvillo-Gámez, Cairns, and Cox (2015) and Dickey (2007), intend to explore educational game design from the player or user perspective. They highlight an interpretive and evaluative analysis of the salient elements with corresponding design norms of an optimal gaming experience and then discuss how such design norms can be extended with or transferred to the instructional design principles.

Empirical studies examining educational game design approaches and features, compared with those evaluating a game's learning effectiveness, are limited. Our recent review of the literature with the search phrase of "game design" + "learning" or "education" generated mostly articles that examined game design as a learning-by-making activity by participants (e.g., Kafai, 2012; Robertson & Howells, 2008) or used game design elements in nongame educational settings (e.g., Deterding, Dixon, Khaled, & Nacke, 2011). Published design research of educational games is frequently a conjectural or an evaluative analysis with existing COTS or serious games (e.g., Annetta, 2010; Dickey, 2007; Mitgutsch & Alvarado, 2012). Pinelle, Wong, and Stach (2008), for example, discerned 10 principles of game usability—"the degree to which a player is able to learn, control, and understand a game"—after reviewing 108 different games from six major game genres (p. 1453). These usability principles, applicable for game design in general, are: allowing users to customize video/audio settings, difficulty, and game speed, allowing users to skip non-playable and frequently repeated content, and providing (a) unobstructed views appropriate for the user's current actions; (b) intuitive and customizable input mappings; (c) controls that are easy to manage and that have an appropriate level of sensitivity and responsiveness; (d) users with information on game status, providing training and help; and (e) visual representations that are easy to interpret and that minimize the need for micromanagement. All of these game usability principles are transferrable to the design practice of educational games and are highly consistent with the infield experimentation findings of our current project.

On the other hand, there is still a lack of studies, especially design-based ones, that present infield testing or design experimentation findings governing the development processes and strategies of educational or serious games (Torbeyns, Lehtinen, & Elen, 2015; Warren & Jones, 2017). In particular, a rich, data-driven, and theory-contributing description of educational game-design exploration and findings should help us develop structural and in situ knowledge of game design. The studies by Andersen, Butler, O'Rourke, Popović and their colleagues (2011, 2014, 2015), for example, examined variant design features and development mechanisms, including game objective, level progression strategy, incentive structure, and scaffolding, of a math learning game (called "refraction"). Based on the play data of online gamers and the perspectives of human-computer interaction and educational psychology, their research efforts and findings helped to illustrate diverse design challenges, the framework of design solution exploration and generation, and solution validation/refining strategies during the educational game design process. In another example, Denis and Jouvelot (2005) conducted a case study on design strategies that were aimed to reconcile learning and fun in a video game dedicated to music education. Building on the self-determination motivation theory (Deci & Ryan, 1985), they explored game design patterns or features that helped to reinforce competence, autonomy, and relatedness in game-based learning. Their design-based research contributed tangible heuristics of educational game mechanics design, such as reifying values into rules to convey knowledge in interactions rather than static data, providing the player expressive ways to confront with and test rules, tuning usability so that entry barriers (e.g., technical difficulty or the game's gender bias) that go against the player's urge to practice gameplay will be leveled, sequential embedding of novel challenges and information in game levels to present a positive slope of the learning curve, and a natural and stealth assessment mechanism of in-game performance. All of these previous learning integration game design suggestions have shed light on our design efforts in this current project and have been corroborated by our project findings.

1.3.3 Enduring Challenges and Interdisciplinary Nature of Game-Based Learning Design

The design of games for learning resembles the innate challenge of entertainment game design: a definite formulation of gaming behaviors or consequences is difficult because interactions between players and the coded game system are often complex, dynamic, and unpredictable. Moreover, play is voluntary and intrinsically motivating and involves proactive cognitive engagement that allows for the freedom of effort and interpretation, whereas these characteristics do not automatically apply to game-based learning (Shute & Ke, 2012). Therefore, existing approaches and tools for developing entertainment games cannot simply be transferred to educational games or game-based learning platforms. There are multiple enduring and distinctive challenges associated with the design of games for learning.

First, problematizing a subject and reinforcing an investigative or epistemic practice with problem-solving are believed to be crucial to game-based learning, as discussed above. But not all domain knowledge or topics share the same approach or advantage in being problematized. Certain learning processes are by nature abstract and sign-mediated and hence cannot always be situated or contextualized. Reality isn't always "fun"—mechanics that impact the dynamics to create the desirable emotional responses may negatively impact the game's ability to recreate the reality of epistemic practices to be simulated. In particular, we lack understanding of how to design a game to reinforce purposeful development of abstract or symbolic domain knowledge.

Second, a game is typically an open-ended learning environment that emphasizes self-regulated experiential learning as well as reflective inquiry. However, not all students are by default self-regulated learners or capable of performing sense-making during game-based problem-solving. Students also differ in their prior domain knowledge, game skills, motives for gaming, and preferences in relation to modes of play. Their attention span with textual information in the game world can be vastly reduced due to the multisensory rendering environment. Given such a heterogeneous player group and the goal to engage and educate all students with a single game-based learning platform, designing a motivating while learning-constructive gaming experience is particularly challenging.

Third, prior research and practice of game-based learning tends to underline a stealth (or incidental) learning idea. Such a perspective is sensible especially when only generic scientific attitudes and generic thinking skills are the focus of learning outcomes. On the other hand, learning by nature is a conscious activity. The desirable player responses in game-based learning should not be just emotional but cognitive, metacognitive, and domain-specific. Inclusion of the idea of informed and intentional learning in games (Annetta, 2010) will entail the integration of gameplay-coherent learning supports in the game that promote purposeful knowledge construction while maintaining motivation and the game flow. A general game design framework (e.g., the MDA framework) has to be extended to address these additional facets of aesthetics or player experience. Corresponding with the inclusion of intentional learning to game-based learning platform design is the challenge to build and coordinate functional usability/interactivity and cognitive usability/interactivity. Rather than creating an intuitive interface, one should also design the interface to be intermediary between gaming actions and action-based knowledge construction.

Ultimately, another unique change of educational game design is to develop embedded assessment for game-based learning outcomes that assess performance-based competency development. Even though recently there is increasing research on the methods of educational data mining in game-based learning assessment, designing and using games as both a learning and an assessment tool are challenging in that gradual learning progression can be in conflict with evidence accumulation for assessment in the game setting. How to achieve an integral design and development of learning tasks and the tasks that discern competency status remains murky.

Interdisciplinary Nature of Game Design Games, acting as an interactive microworld, a digital toy, and an environmental storytelling device simultaneously, call for the integration of multiple disciplinary perspectives and approaches. A game artifact involves the application of communication/information design, visual design, human-computer interaction, and software engineering. Designing games as an effective learning platform, given all of the abovementioned challenges, entails interdisciplinary knowledge and methods of additional disciplines, such as the subject domain knowledge, learning system design, psychology, and educational measurement. Interdisciplinary collaboration among the design team members from these different fields, by itself, is a challenging process. It has to balance and incorporate their often conflicting values, ways of thinking, domain-specific language, and methods, especially those of game designers, instructional designers, content experts, and psychometricians. Although cross-cultural communication and interdisciplinary design are recurrent topics in workplace studies and engineering education research, the functional processes and patterns of interdisciplinary design for game development are generally absent in the literature.

1.4 Goal and Structure of the Current Book

In spite of the plethora of research on game-based learning, the design descriptions or operational conjectures on how to effectively and intrinsically design intentional, domain-specific learning in gameplay are scarce. Multiple enduring challenges associated with educational game design remain unaddressed. The previous efforts to explain the framework of game-based learning typically focus on an evaluative analysis of existing games or present a general and theoretical level of reasoning, thus lacking tangible guidance for the actual educational game design. Game design is multidisciplinary in nature, yet few efforts have contributed to describing the interdisciplinary design process, techno-pedagogical design knowledge, or accessible design language.

Based on the four-year design and research of an architecture simulation game for mathematical learning (called E-Rebuild), this book is aimed to present a phenomenological examination and explanation of a functional design framework for games in education. It aims to provide a rich description of the experiences and perceptions of designing a digital learning game and of performing interdisciplinary collaborative design among experts of different fields.

Specifically, it will address both practical and conceptual issues about the design of play-based learning systems that align and interweave game and learning mechanics, evidence-centered design of learning tasks and assessment, and in-game learning support. It also aims to explicate the process of coordinating the interdisciplinary language and perspective differences in design communication and negotiation for the future development of learning games.

In Chap. 2, we provide an overview of the integrative, interdisciplinary design process of E-Rebuild and the adopted phenomenological research approach. Core phases of designing a game-based learning platform are illustrated with a longitudinal log of the iterative design, experimentation, and refining of E-Rebuild. In Chap. 2 we also present a positioning statement and design reflection notes of each co-author (and interdisciplinary design team member). In Chap. 3, we explain salient interdisciplinary design activities and patterns that emerged from the E-Rebuild project. The description of the interdisciplinary design patterns in this chapter consists of a contextualized design narrative/account of core design processes and an analytical synthesis of core design pattern elements—a *design problem statement* with its context and specifics, the *solution* or technique (with its key structure or mechanism) to solving the stated problem, and the *pattern* of transferring or scaling this design solution or design move. In Chap. 4, we report design challenges associated with the core components of gameplay and review the gameplay design propositions and infield test findings of E-Rebuild. We discuss how domain-specific learning is integrated in and activated by core game actions, rules, game objects, and the game world design. In Chap. 5, we describe an integrative-design approach that interweaves game-based task design with in-game assessment of learning. We discuss core design processes and functional conjectures on the approaches of task generation and evidence accumulation, with support of infield observations on the implementation feasibility and outcomes of the design assumptions. In Chap. 6, we explore the design of dynamic game-based learning support. We review prevalent practices and prior research of scaffolding and support in game-based learning, share our observations of the obstacles that learners experienced in game-based learning processes, and report the corresponding learning support strategies with infield testing findings of E-Rebuild. In the conclusive Chap. 7, we discuss an emerged, functional design framework for game-based learning platforms, with a summary of the design problem structuring process for the interdisciplinary, integrative design of game-based learning. We conclude the chapter and the book by discussing potential directions of future design and research efforts of game-based learning design, with a set of core design concepts highlighted.