Chapter 15: Game Learning Analytics

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ABSTRACT

Games are a pervasive cultural phenomenon with intriguing connections to learning, and the use of learning analytics can inform our understanding of learning in the context of games. In this chapter we identify four principles that are fundamental to both compelling gameplay and meaningful learning – **agency**, **engagement**, **growth**, and **social connection**. Agency in learners helps them grow and feel safe to fail, persist, and feel ownership of their learning. Engagement, both as great interest and active involvement, is essential to learning, and digital games can be very engaging. Growth involves increases in ability that are developed through effort, perseverance, trying alternative strategies, and seeking help from others. Social connection with other players both within and outside of games facilitates learning. We propose that these four principles serve as an entry point for understanding and conducting game learning analytics work. For each principle we provide examples of evidence-based approaches to the design, measurement, and analysis of learning in game-based contexts to guide thinking and work in the nascent field of game learning analytics. This chapter is intended to be useful not only to game learning analytics practitioners but also to people working in LA-adjacent domains, such as game design, classroom learning, data security, and educational policy. We suggest that designers, practitioners, educators, and learners could all benefit from the translation of academic GLA work into a form that is useful to this broader constituency.

Keywords: Digital games, learning, analytics, agency, engagement, assessment, collaborative learning, social learning

Games have been played within all cultures, over millennia, in myriad contexts, for varying reasons. This ancient form of human interaction, used to convey and stabilize cultural norms, has also long been both a source of enjoyment and an instrument of teaching and learning. Even some of the oldest known games – from the 6th century B.C. sport Polo, which taught war skills [17], to the 11th century A.D. board game, Rithmomachia, which taught number theory [77] – facilitated learning. Using games to support learning is now an established practice, and the use of digital learning games, from Oregon Trail to Minecraft to America's Army, propels an ever-growing interest in evaluating the impact of gameplay on learning [80].

Game Learning Analytics (GLA) is the application of learning analytics (LA) methods to gain insight about learning in the context of digital gameplay. Across many definitions of 'game', we find Salen and Zimmerman's [73, p. 80] most concise and effective: "A system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome." Game data are different from other LA data, since they comprise detailed information about players' frequent decision making and actions in a media-rich world. Additionally, learner actions tied to the specifics of the game world context enable GLA to be more contextualized than other dense, open ended data streams (such as emotional LA).

Since the purpose of educational games is to positively impact learning, it is important for learning game designers, educators, as well as learners themselves to understand if, how, and to what extent learning happens. Game learning analytics affords a unique perspective on learning impact, as it provides a look at learning over a broader time period, by finer-grained measures, and at a larger scale than other learning game research methods. GLA is a key tool in an ecosystem of design and evaluation, since it can provide analytical insight into exactly which aspects of games do or do not support learning, in a way that other research methods, like pre-post assessment of learning, cannot. GLA can enable data-informed game design and inform feedback to learners, educators, and others who work to support learning. Additionally, GLA methods can transfer to LA work in non-game contexts, such as highly interactive learning (e.g., sensor-equipped spaces providing dense data streams) or highly contextualized learning (e.g., makerspaces and project-based classrooms, where the learners' actions are contextualized in the pursuit of long-term goals but involve many individual sub-tasks).

Game learning analytics is a young field, without a lot of standards, and practitioners need to be nimble and scrappy. In this chapter we identify four key principles that are shared by games and learning that we propose can serve as a toolkit for approaching game learning analytics work. It is our hope that this framework serves as a helpful guide to practitioners as they identify what they value in games for learning and the questions they want to answer. For each of these four principles we provide evidence-based approaches and examples to guide practitioners' design, research, and analysis of game-based learning.

1 FOUR PRINCIPLES OF GAME-BASED LEARNING

We propose that there are four fundamental principles that are essential to *both* compelling gameplay and meaningful learning: **agency**, **engagement**, **growth**, and **social connection**. These four principles correspond roughly to the four "pillars of learning" that Hirsh-Pasek et al. [35] derived from learning sciences research, but we have adapted them specifically to address game-based learning. Understanding the critical role of agency, engagement, growth, and social connection in both games and learning provides insight into designing learning games, shapes how we measure and analyze learning using GLA, and illuminates why and how games can be valuable learning tools. Each of these factors alone fuels successful gameplay and learning experiences; combined they provide even more powerful effects.

1.1 Agency

In good games, players feel and act with agency. Games both enable decision-making that shapes and reflects players' active sensemaking and help players formulate and express personal ideas and desires. Like ritual and play, games occur in circumscribed spaces, "temporary worlds within the ordinary world" [38], an idea later popularized as the "magic circle" [73]. The magic circle supports agency by providing players a "psychosocial moratorium," a developmental concept introduced by Erikson [29] and applied to video game contexts by Gee [32]. Within the magic circle, players craft a personalized narrative in dialogue with the game's design [7], assume temporary power, experiment with identities or roles, and explore their sense of ethics and morals with reduced risk versus real-world exploration of such ideas.

Agency is foundational in a constructivist view of learning. The **constructivist** theory of cognitive development [59] maintains that children actively construct their own knowledge by exploring, developing and testing theories, and internalizing the results of their actions. Learning games embody this philosophy by providing environments in which players explore and experiment, providing a "Rich Environment for Active Learning" [33].

1.1.1 Design For Agency

The design of games and GLA can support the development of agency in learners – helping them grow, feel safe to fail, persist, and feel ownership of their learning. Agency is closely tied to concepts of self-efficacy, active learning, and meaningful learning.

Bandura's concept of **self-efficacy** [3] suggests that the more people believe they can succeed, the more likely they are to engage and the more effort they will invest. Game design can support players' self-efficacy by ensuring that even beginning players are able to succeed and then raising the bar for continued demonstration of competence as mastery grows.

Active learners take control of their own learning process by monitoring their understanding, seeking out opportunities to experiment and explore, and applying what they discover to shape their own knowledge. Well-designed games provide players with rich environments to explore, a system for keeping track of their discoveries, and a degree of control that enables them to progress at their own pace.

Meaningful learning involves connecting new information with what you already know and with your relevant real-life personal experience [11]. One example of games that hold special promise for meaningful learning is those using augmented reality, since they incorporate elements of the player's actual real-life environment. To optimize meaningful learning, game design should incorporate player interests and preferences and enable players to actively reconstruct the game world alongside their broader, real-world experiences [19]. As a result, it is critical for designers, researchers, and educators to be aware of the influence of learners' background (sociocultural factors, gaming experience, personal connection with content and theme, etc.) on their sense of agency in a game.

Two design approaches that aim to ensure active, meaningful learning and self-efficacy for all players are Human Centered Design (HCD) and Universal Design for Learning (UDL). HCD is based on understanding the needs of users, involving users in iterative design, and adapting technology based on user feedback [83]. UDL provides recommendations and methods for including diverse learning needs, goals, and abilities to better support all learners [71] and improves learning processes for a diverse population of students [14].

1.1.2 Measurement and Analysis of Agency

Agency, operationalized in self-efficacy, active and meaningful learning, is reflected within gameplay through the goals player-learners set for themselves and styles of play that they choose. Analyzing these behaviors sheds light on how they adopt different roles and perspectives, and enables **player categorization**.

GLA work related to agency is primarily focused on categorization of player behavior (often called **player models**) by examining actions in pursuit of goals like character customization, game badges and achievements, or competing with other players. LA work on player modeling focuses on assessing player agency by recognizing learners' play styles and identifying goals or plans that players are pursuing, and then eventually supporting their agency by adapting the game to suit a particular player's gameplay style.

In the field of video game studies, there are many ways to categorize and identify **play styles**. This work originates with four archetypal player types proposed by Bartle [5]: achievers, explorers, socialisers, and killers – which has since been critiqued and extended using qualitative and quantitative analyses of gameplay and survey data [34].

The field of learning games extends this categorization work. Player-learner models are built from a mix of gameplay data and theory-based cognitive models. GLA methods are used to generate groupings of player-learners, like identifying players who play by rapid guesswork versus those using slower strategic moves, which provides insight on players' prior domain knowledge [46]. For a systematic review of GLA player-learner modeling work see Hooshyar, Yousefi, and Lim [37]. Player-learner models can be used to adapt games to different learner preferences, competencies, and understandings. For instance, procedural content generation (PCG) is a productive way to practice data-driven adaptive game design. In PCG, the game "terrain" (the space, components, and obstacles in a challenge) is dynamically generated to suit a player's experience and inferred preferences [92]. Games and GLA can be designed and developed to identify learners' preferences and current understanding, as well as scale enemy difficulty, puzzle complexity, and other factors to support productive learning pathways.

There is a lack of GLA work examining player categories through the lens of equity. Qualitative analyses help us understand how to support richer participation and engagement by diverse sets of participants; for instance, characters, themes, and narratives that reflect the experiences of under-represented groups (particularly along gender, race, and ethnicity lines) help support agency in gameplay [66]. Future work in GLA should similarly address issues of equity and justice, and better address the range of players' physical and learning abilities. GLA analyses can also examine the interaction of personal values and preferences with game design elements (like theme and narrative) to engage players on a more personal level and to support fuller personal expression by learners, especially those minoritized in game cultures.

Since all of this work involves sensitive information about players, it is critical that game designers, developers, and educators advance and implement ethical LA (Chapter ??, this volume) and ensure learner privacy, data security, and transparency for learners about how data is collected, interpreted, and used.

1.2 Engagement

Engagement, both as great interest and active involvement, is critical to learning. If you are not interested and not doing anything, you will not learn! Games can enhance players' motivation to learn as well as persist beyond failure. In games, failure is normalized, pleasurable, and even celebrated [39]. Games can also teach us, with low stakes, things we need to know in real life, and this type of learning can feel enjoyable – pushing the limits of pattern mastery and sensemaking can be fun!

It's a commonplace assertion that digital games can be very engaging. The concept of engagement, however, is ill-defined and complex at best [9], so designing for, measuring and analyzing engagement are not straightforward endeavors. Engagement includes cognitive, behavioral, and affective components [31]. One of the challenges to developing and understanding GLA regarding engagement is that game designers typically focus on addressing the cognitive and affective components of engagement, while researchers tend to measure and analyze behavioral components. Resolving this discrepancy is an important area of opportunity for future design and GLA work.

1.2.1 Design for Engagement

Given the ill-defined nature of the concept of engagement, it's not surprising that researchers operationalize engagement with digital games in many potentially overlapping and/or contradictory ways. These include intrinsic motivation [60], attention, immersion, involvement, presence, flow [8], memory, motor speed and control, persistence, and positive and negative affect [22]. Likewise, design features that are suggested to support engagement include factors as diverse as role-playing, narrative arcs, challenges, interactive choices and interaction with other players [25], leveling up [57], and adaptivity [13]. **Intrinsic motivation** is the most well-researched of these constructs, and ties together many of these features, so we explore that concept in more depth.

What makes digital games engaging, fun, or intrinsically motivating? Why do people want to play them with no encouragement, prompting, or external motivation? Deci [23] argues that some activities provide their own inherent reward, independent of any kind of extrinsic rewards. Well-designed digital games exemplify this type of activity. Malone and Lepper [47] propose a taxonomy of intrinsic motivation factors that make learning games fun, including individual motivations such as challenge, curiosity, control, and fantasy, and interpersonal motivations like cooperation, competition, and recognition. Intrinsic motivation, so common in gameplay, is also linked to school success [1]. As a result, researchers have investigated the integration of intrinsically motivating games into the classroom [25].

Student perceptions of the concept of intelligence also impact school success, and learners with a growth view of intelligence (malleable via effort) are more likely to take risks, try new approaches, and persist at challenging tasks [28]. Moreover, praise for effort or progress is more likely to encourage a **growth mindset** than praise for task performance or ability, which has important implications for the wording of instructional and reward messaging in learning games. The growth mindset approach has been effectively applied to game incentive structures that identify and reward effort, strategy use, and gradual progress [49, 50].

1.2.2 Measurement and Analysis of Engagement

To quantify engagement, GLA work starts with characterizing behavioral engagement via amount of gameplay – for instance, number of players, means and variance in gameplay time, play time per session, and numbers of play sessions – but we can get a deeper understanding of the cognitive and affective components of engagement through observational and qualitative measures, sensor-based data, and more detailed gameplay data.

Using observational and qualitative measures, engagement in games has been examined through the lens of **flow** [42] – the immersive, deep engagement that is maintained by an appropriate amount of challenge of a problem at hand [20]. In addition to using time on task and flow, one can layer in a variety of behavioral, cognitive, and affective perspectives to understand engagement in learning games [58].

Detailed gameplay data can provide insight on engagement in a variety of ways. For example, progression through different sections of the game – levels, obstacles, or terrains – are indicators of where players spend time and where they succeed or fail. One way to quantify game progress is by using heatmaps to identify where players proceed or get stuck [61]. Other LA techniques, including clustering and state network diagrams can be used to measure engagement [52]. These two papers also provide examples of how these analyses can inform game design.

In addition to documenting player agency, player categorization can be used to help keep players engaged. Predictions of engagement and gameplay dropout are often part of player models [37]. Dynamic difficulty adjustment is a popular data-driven technique that uses player models to maintain an appropriate level of challenge to keep learners interested [96]. For instance, the Hamlet system [15] describes how to model a player-learner's current and upcoming state of progress or struggle using their play data. Then enemy difficulty level in the game is adjusted to match players' skill and understanding level, thus keeping them engaged in the learning aspects of gameplay.

Note that some engagement data can be misleading with respect to learning. For example, games may entice players to spend time in activities that don't lead to productive outcomes. Game design elements with questionable purpose have been described as dark design patterns [94]. Mismeasurement is especially likely with educational games, since engaging features may not address learning goals [43]. Thus, it is the responsibility of learning-game designers and researchers to make principled use of design elements and measurements of engagement to ensure that they are used in the service of learning.

1.3 Growth

Agency makes people feel they can learn and engagement motivates them to want to learn. How can we design learning games to support, use data to measure, and conduct meaningful analysis regarding learners' growth of skills (what learners can do) and performance (how they demonstrate skills)?

Growth involves increases in ability that are gained through effort, perseverance, trying alternative strategies, and seeking help from others [28]. Cognitive, behavioral, and affective growth can be achieved through learning. In good games, growth of skills and performance advance game play and make playing games challenging and fun.

The effectiveness of games in supporting learning is still debated. While some educational games are documented to be effective learning instruments, findings can be inconsistent [74]. Further, while GLA can help clarify and elaborate on the extent to which games can support learning in various domains, contexts, and for diverse groups of learners, there is mixed data around the degree to which players are able to **transfer** skills, extending learning in one context to other contexts, particularly skills learned within games into non-game contexts [4].

1.3.1 Design for Growth

Games effectively promote learning when they integrate cognitive engagement with playfulness, and when content engagement is linked to game action [41]. Games that blend these factors can serve as personally meaningful "objects-to-think-with" [53, 36].

Successful learning games reflect evidence-informed game design principles, which incorporate the best available efficacy evidence from research, content experts, practitioners, local context, and users [21]. One productive approach to designing learning games is employing **design-based research**, in which prototype versions of a game are tested iteratively with users to inform further design [63]. Design-based research involves understanding learning processes in authentic contexts, such as schools, homes, or museums, and working to improve game-based learning outcomes within those contexts [78].

As a learner explores a game, mentors or digital agents can support learning through the use of scaffolding techniques. **Scaffolding** provides learners with as much or as little support as they need to succeed on a task and reduces this support as the learner becomes more capable [88]. Designing scaffolding into digital gameplay is a particularly useful technique for supporting learners of varying skill levels playing the same game [54, 65].

Guided play experiences, which combine the approaches of constructivism and scaffolding, are optimal for learning [30]. Guided play combines elements of free exploration with elements of mentorship, to ensure that exploration and hypothesis testing is structured and systematic. Guided play provides a natural opportunity for playful conversation, and a prime context for learning [90]. With the introduction of artificial intelligence in games, the design of interactive, social, intelligent agents [12] might be able to effectively guide game-based learning, eventually providing something approximating the kind of scaffolding that a human play partner provides [86].

Building algorithms into learning games that enable them to adapt to address individual learner's skill levels holds special promise for learning outcomes. Research regarding the design of adaptive level progressions that optimize engagement and learning is ongoing [13]. In-game, real-time, individualized response to success and failure is another critical game feature that supports learning [64]. For feedback to be effective it should be scaffolded, encouraging, and incremental. With regard to failure, a wrong answer is a learning moment. If you don't get anything wrong, you aren't learning – your performance is evidence that you were already competent in the content before playing the game!

1.3.2 Measurement and Analysis of Growth

Measuring growth involves examining how players develop competence and understanding. GLA can be used to measure growth by assessing users' success on in-game tasks and the ways in which scaffolding, feedback, and challenge affect learners' patterns of experimentation, strategies, and success.

Data visualizations and learner-action classification using Bayesian network analyses, clustering methods, or Markov models, are a few commonly used data mining methods to depict and measure growth of skills in educational games [16, 51]. Here, we describe three examples of analyses that span a variety of game types and learning contexts.

First, Bayesian networks can be used to identify learner progress by analyzing gameplay data signifying player actions, successes, and failures [75]. This work leverages the Stealth Assessment Framework [76], which involves developing learner models that describe what learners know, competence models that articulate the learning domain, and evidence models that map player game actions to learning. The **Stealth Assessment Framework** proposes a design and analytic framework for embedding assessment activities in engaging game tasks, with the goal of blurring the distinction between assessment and learning in gameplay.

Next, cluster analyses of gameplay data can be used to identify different learning phases such as Exploration, Tinkering, and Refinement, as described in the EXTIRE framework [6]. This framework was developed based on a constructionist programming game played in classrooms, and presents methods enabling automated identification of the learning phases via game actions and tasks.

Finally, Hidden Markov Models (HMMs) can be used to identify productive and unproductive progress in gameplay [85]. Tissenbaum et al. [85] use HMMs on museum-based gameplay data to identify productive player actions (for instance, remembering successful approaches or trying out novel approaches) as well as unproductive player actions (like repeating the same successful approach with no change). Since productive actions indicate learner growth and unproductive actions often correlate with visitors leaving the exhibit, identifying these patterns helps in understanding and supporting growth of skills and performance.

These measurements of learner growth are useful in communicating with different participants in the learning environment, including parents [68], teachers [62], and docents [44]. These participants have access to real-world interactions not easily accessible in GLA data – which makes integrating GLA with their contextually informed intervention particularly valuable. Developing platforms to convey this information, typically through dashboards, is extensively discussed in Chapter ??, this volume.

1.4 Social Connection

Almost all of human learning takes place in social contexts. Games have traditionally played a critical role in enshrining social practices like rituals and etiquette [18], which in turn provide valuable kinds of sociocultural learning [69]. Digital games offer a spectrum of social opportunities, from in-classroom social interactions where learners express and build identity through avatars [40], to experiencing apprenticeship, mastery, and real world (meatspace) community through massively multiplayer role-playing game cultures [81].

1.4.1 Design for Social Connection

Social connection with other people facilitates learning. Human brains have evolved to learn in social contexts with other people, and designing games that support social learning can build on this brain-based human tendency [48]. Examples of design features that support collaborative play and learning include creating a common goal for the group [95], providing common ground for shared understandings among players of different ages and experience levels [2], including explicit role assignments for different players [10], providing collaborative interfaces and tools [82], structuring guidance for both individual and collective action [87], and designing intelligent agents to interact with players in a social way to capitalize on parasocial relationships [45].

Social connection with other players outside of games also facilitates learning. Minecraft players participate in social communities through tutorials they make for each other [55]. Minecraft and other social games can also provide inroads for socialization for children with autism [67]. Remarkably, players of complex, multiplayer online games achieve reading levels almost three grade levels higher when socially engaging with other players on discussion boards [79]. Salen [72] further describes many kinds of rich, productive social activities learners engage in while playing or communicating about games – including working and solving *in-game* problems with physically collocated family; discussing, cooperating and competing with classmates and friends in games; and engaging in creative and interactive online communities where players learn from each other and participate in rich communities around their games.

1.4.2 Measurement and Analysis of Social Connection

There is a dearth of GLA work on social connection in gameplay. Measuring social connection involves recognizing dynamics such as role enactment, collaboration and competition, collective and individual guidance, social sharing, and parasocial connection. However, some of these interactions take place off-screen, and are hard to capture completely through gameplay data. Thus, they are often assessed in concert with qualitative analyses of observational data, and multimodal LA based on motion tracking, wearable, and/or other sensor data.

There is a rich body of qualitative work examining social configurations through digital games in different learning environments. Social interactions within and around games in classrooms can involve sensitive topics of representation, inclusion and identity [84, 40]. Hybrid physical and digital game activities can also be designed to support social interactions and collective understanding through physical movement around digital games. Games, like BeeSims [56], can connect embodied physical movement with digital simulations of complex phenomena and are able to support different kinds of roles and collaborations [24]. Hybrid games have also been used in LA analyses of collaboration through methods discussed in Chapter ??, this volume.

Social game play has been measured using a variety of data analytics methods. For example, players' demonstration of collaborative strategies and expertises can be identified through methods like social network analyses, networked engagement metrics, and other measures of communication coupled with game progress – especially in online multiplayer game environments like World of Warcraft [27, 93]. As the development and adoption of online multiplayer games in classrooms and other learning environments rises, this work will become more and more applicable to learning settings [70].

Within GLA, gameplay data has been used to identify different kinds of social learning. Models of social learning behavior can be built by conducting qualitative research on the game, the physical space that it is situated in, and user interaction patterns typical of players in the game's context. These models can be mapped to patterns in gameplay data, and then used in future studies to recognize instances of social interaction and learning, without needing to rely on further qualitative visual observation. This is exemplified in the analysis of data from a museum game where visitors can play on an interactive digital tabletop in a way that facilitates individual play, talking to other players, seeing others' work, and working collaboratively or competitively [85]. These different kinds of social play and learning, even when occurring outside of game interactions, can be identified through patterns in gameplay data – for instance, people who looked at others' work and talked to others have distinctive sequences of repeating and modifying their own and others' strategies.

There is a pressing need for LA work on **computer-supported collaborative learning** [91]. Work in this space has the potential to expand GLA for social connection, which is particularly important given the proliferation of social learning games [89]. Fostering social connections through inclusive social networks can help address issues of equity in games. For example, gender-equitable communities with strict moderation around all forms of harassment and trolling have proven popular across gender and ethnicity groups [66]. Developing LA methods to identify and support productive social connection in such spaces is a key opportunity to enhance the creation of more equitable game-based learning experiences.

2 OPPORTUNITIES

Game learning analytics is a nascent field. To provide some structure to GLA thinking and work, we have proposed the four principles of **agency**, **engagement**, **growth**, and **social connection** as an organizing framework, but there are additional issues to be addressed.

Standardizing the assessment of efficacy in learning games is a prime opportunity in GLA. Doing so will require multidisciplinary collaboration among those working in LA with those in adjacent domains like curriculum design, game design, educational research, data security, and educational policy. This work can build on existing standardization frameworks in the video game industry [26] and could also enable the evaluation of learning across multiple games and contexts.

Standardization of GLA can also inform transfer, which is a central issue in learning sciences. Standardized intergame GLA has potential to illuminate near transfer from game to game and also pave the way for identifying far transfer to different activities when integrated with other school and activity data.

GLA also has potential benefits for a broader range of stakeholders than its current primary use in academia. The aim of this chapter is to be informative not just to LA practitioners but to anyone working with games for learning, including those who design games, select and integrate games for classroom use, assess the effectiveness of games, manage data to help kids play safely, and set guidelines for healthy play. Our hope is that GLA will evolve to be transparent, digestible, controlled by, and empowering for all involved participants – teachers, parents, and (in particular) learners themselves.

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