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All Games Are Not Created Equally: How Different Games Contribute to Learning Differently in Engineering

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All Games Are Not Created Equally: Differences in How Games Contribute to Learning in Engineering

Abstract

Reviews of game-based learning literature treat games as a unified technology whose learning contributions are comparable across cases. However, there are actually many types of games that contribute to and transform learning processes differently. This qualitative, secondary analysis of a systematic literature review catalogs six ways digital and non-digital game implementations have contributed to learning in engineering education, and classifies how radically each type of contribution has transformed learning processes in engineering classrooms. For researchers, results reinforce that contextual variables like learning objectives should be considered when studying game-based learning. For instructors, results support the merit of non-digital games as resource-effective means of transforming engineering learning processes, and suggest that teaching processes will likely change based on the game's intended learning contribution.

Introduction and Purpose

In the past decade, games have developed an increasingly strong theoretical and empirical basis for effectiveness as pedagogical tools (Plass et al., 2015; Whitton, 2014). Studies have found game-based learning (GBL) to offer learning benefits in multiple disciplines, including immersive contexts to learn new languages (Peterson, 2010), authentic disciplinary problem-solving environments (e.g., Coller & Scott, 2009), and play spaces to develop social skills like teamwork (e.g., Hadley, 2014). The use of games in STEM education is of particular interest, as GBL has grown popular among mathematics instructors (Takeuchi & Vaala, 2014), has been the target of U.S. federal funding for science education (Young et al., 2012), and has taken root in engineering disciplines (Bodnar et al., 2016). Conventionally, most GBL research has focused on demonstrating the merit of games when compared to traditional teaching and learning activities (Ke, 2009). However, as GBL research continues to mature, researchers have urged the community to explore more nuanced lines of inquiry, such as evaluating the learning impact of game design components (Clark et al., 2016; Mayer, 2014) or teaching practices (Hanghøj & Brund, 2011; Kangas et al., 2016).

Our study was motivated by the observation that these broader lines of inquiry continue to treat GBL as a single, unifiable pedagogy, implying that learning fostered by one GBL activity should be comparable to learning fostered by others. Studies of the effectiveness of individual game design components—known as "value-added" studies (Mayer, 2014)—seek to understand how adding a particular design component affects the educational effectiveness of a game. While this type of inquiry is effective for understanding how to modify individual games, reviews and meta-analyses examining added value game design reveal that researchers strive to find common game design components whose benefits can be generalized to game-based learning more broadly (Clark et al., 2016; Hays, 2005; Vogel et al., 2006). Similarly, studies of effective game-based instructional practices—which we call pedagogical studies—often seek to define modes of instruction during GBL activities with minimal reference the types of games under study (e.g., Hanghøj & Brund, 2011; Kangas et al., 2016).

In our (the authors') experience, however, we have seen games that contribute to learning in several disparate ways, from fostering specific skills to offering a common prior experience to introduce a new concept. Further, while some games are relatively simple attachments to existing learning activities, others are intricate systems that help transform the learning process into something unique (Clark et al., 2016; Garris et al., 2002). Some influential authors have attempted to theoretically capture the variety of ways games can contribute to learning (e.g., Gee, 2003; Prensky, 2001), but little work has examined how current empirical applications of games for learning have actually contributed to the learning process. Understanding these differences in contributions to learning limits can benefit both game-based learning research and game-based instruction. For researchers, by understanding the ways in which different games contribute to learning differently, results from other lines of inquiry in game-based learning—such as value-added studies and pedagogical studies—may be generalizable beyond individual games in a more meaningful fashion than generalizing broadly to all games for learning. For instructors, understanding how a particular game contributes to learning can inform how instruction should occur—e.g., what to focus on when debriefing or what kind of scaffolding is necessary to support gameplay.

To investigate this problem, we elected to survey publications on games in engineering. We chose this discipline for two reasons. First, engineering—like other STEM disciplines—has seen a plethora of GBL implementations (Bodnar et al., 2016). Second, Bodnar et al. (2016) recently published a systematic literature review that comprehensively overviewed the landscape of empirical work on GBL in engineering education, and the transparency of their published methodology makes their review well-suited to a secondary analysis—i.e., using the pre-existing collection of papers to answer new research questions (Heaton, 2008).

Using this systematic review for a qualitative, secondary analysis, we addressed the following research questions:

1. What have been the primary contributions of digital and non-digital games to the learning process in engineering education?
2. To what extent have digital and non-digital games transformed the engineering education learning process?

We have answered these research questions by open coding for the primary learning contributions of published GBL implementations in engineering education, and by a priori coding for how transformative each game is, according to an appropriate theoretical framework.

Theoretical Framework

The theoretical framework we used to answer our second research question was the Replacement, Amplification, and Transformation (RAT) framework for instructional technology integration proposed by Hughes et al. (2006). Drawing from findings on technology integration in prior literature as well as observations from the lead author's research, the RAT framework categorizes technology use—in this case, game implementation—based on the degree to which it transforms or enhances learning tasks. The framework has three such categories, in increasing order of enhancement:

1. **Replacement** – The game does not enhance or change learning tasks in any meaningful way, serving "merely as a different means to the same instructional end" (Hughes et al., 2006, p. 1617).
2. **Amplification** – The game does not change the learning tasks, but enhances them in ways not feasible without the game. Enhancements can provide learning aids, such as contextual help systems and visualizations; or can increase learning productivity, such as through automation of calculation or assessment.
3. **Transformation** – The game allows for the inclusion of learning tasks that would not be feasible otherwise. Transformation can involve the introduction of new subject matter, teaching practices, or learning processes.

Several studies have demonstrated that the RAT framework is useful in categorizing instructional technology integrations with respect to how technologies modify learning tasks (e.g., Kimmons et al., 2015; Smidt et al., 2012). In this study, we applied the RAT framework to games, which we consider to be instructional technologies because they are a form of media used to complement instruction (Gagné, 2013). Specifically, we used the RAT framework to categorize how transformative each game was, compared to typical active learning tasks in engineering classrooms, such as quizzes, labs, design projects, closed-ended problem-solving tasks, case studies, and programming tasks.

Method

Our study is a secondary data analysis of the systematic review data collected by Bodnar et al. (2016). We selected this review because it is transparent in its methods disclosure and comprehensively covers studies on games in engineering education over a recent 14-year timespan. We will overview relevant methods from the original review, and we encourage readers to consult the original publication for more detail.

Data Collection

The purpose of the original systematic review by Bodnar et al. (2016) was to compile and describe games and gamification architectures researched for use in engineering education in order to determine how games affect student learning and attitude. The authors defined a game as involving "a goal, set of rules, play component, and winning condition" (p. 148). Drawing upon methods suggested by other relevant literature reviews, the authors used broad keywords related to games and engineering education to search several databases—including ScienceDirect, Scopus, Web of Science, EBSCO, ERIC, and Engineering Village—and found 5,999 unique papers published from 2000 to 2014. They filtered publications to include only English-language papers that met their definition of a game and were used in undergraduate classrooms. These publications comprised their primary data set of 190 papers[1], which the authors listed and categorized as using digital games, non-digital games, and/or gamification.

[1] Bodnar et al. (2016) stated that their primary set included 191 unique papers, but our independent count found that one paper was mistakenly double-counted, and there were in fact 190 unique papers

Most of these papers came from the disciplines of computer/software engineering, mechanical engineering, or electrical engineering.

Data Filtering and Analysis

We analyzed each publication in the primary set from Bodnar et al. (2016) describing digital games (139 papers) and non-digital games (42 papers), cataloguing each publication in a spreadsheet with a brief description of each game it presented. We found that many publications presented the same game implementation in different contexts, or did not describe a game in enough detail for our analysis. These papers were excluded such that each sufficiently described game implementation was included in our study only once. Moreover, we found that some publications included both digital and non-digital games, or were classified in error by Bodnar et al. (2016) as including a digital game, when the game described was actually non-digital. We reclassified these publications accordingly, leaving us with 112 publications in total—76 publications including only digital games, 34 including only non-digital games, and 2 including both digital and non-digital games. Figure 1 summarizes the overall process used to reduce the original data set found by Bodnar et al. (2016) to the 112 papers reviewed in this paper.

We then analyzed the data in accordance with open and a priori coding procedures outlined by Miles et al. (2014). To answer our first research question, we open-coded each game for its primary learning contributions (PLCs.) We defined a PLC as the main way a game is intended to contribute to players' learning experiences, and it is determined by a combination of the game's features, how the game is used in context, and the learning objectives for the game's use. Accordingly, the same game can have different PLCs if the learning objectives and use contexts are sufficiently different. For example, the game *Delta Design*—a board game that involves building a structure based on well-defined rules and objectives—was used in substantially different contexts across two publications. Lloyd and van de Poel (2008) had students work together to play Delta Design, and then introduced an extra narrative that the structure they built collapsed, tasking students with finding out who was at fault for the collapse. Grau et al. (2012) also had students work together to play *Delta Design*, but modified the rules to give each player competing "hidden objectives" for the structure to introduce mild competition, and made the rules for structure building align more closely to real-world statics concepts. While both authors used the same base game, their implementations had different learning objectives and use contexts, leading to different PLCs. Particularly, the former served as an analogy for real-world crisis management, while the latter was both an analogy for multidisciplinary teamwork and an opportunity to apply statics concepts.

We determined a game's primary learning contribution by examining patterns in the different kinds of learning processes enabled by each game. For example, several games sought to give students opportunities to practice solving engineering problems with automated feedback about their solutions. We coded these games' PLC as "practice-feedback loops," as the learning processes they engendered revolved around the student improving in a particular skill by practicing it, getting feedback, and then practicing further. A game could have multiple primary learning contributions, if it was described as being used for multiple learning goals. At the end of our coding process, we identified six common primary contributions to learning from these games. In accordance with recommendations from Borrego et al. (2014) on using content analysis in systematic reviews, we presented these six PLC codes quantitatively based on their frequency in the papers we analyzed.

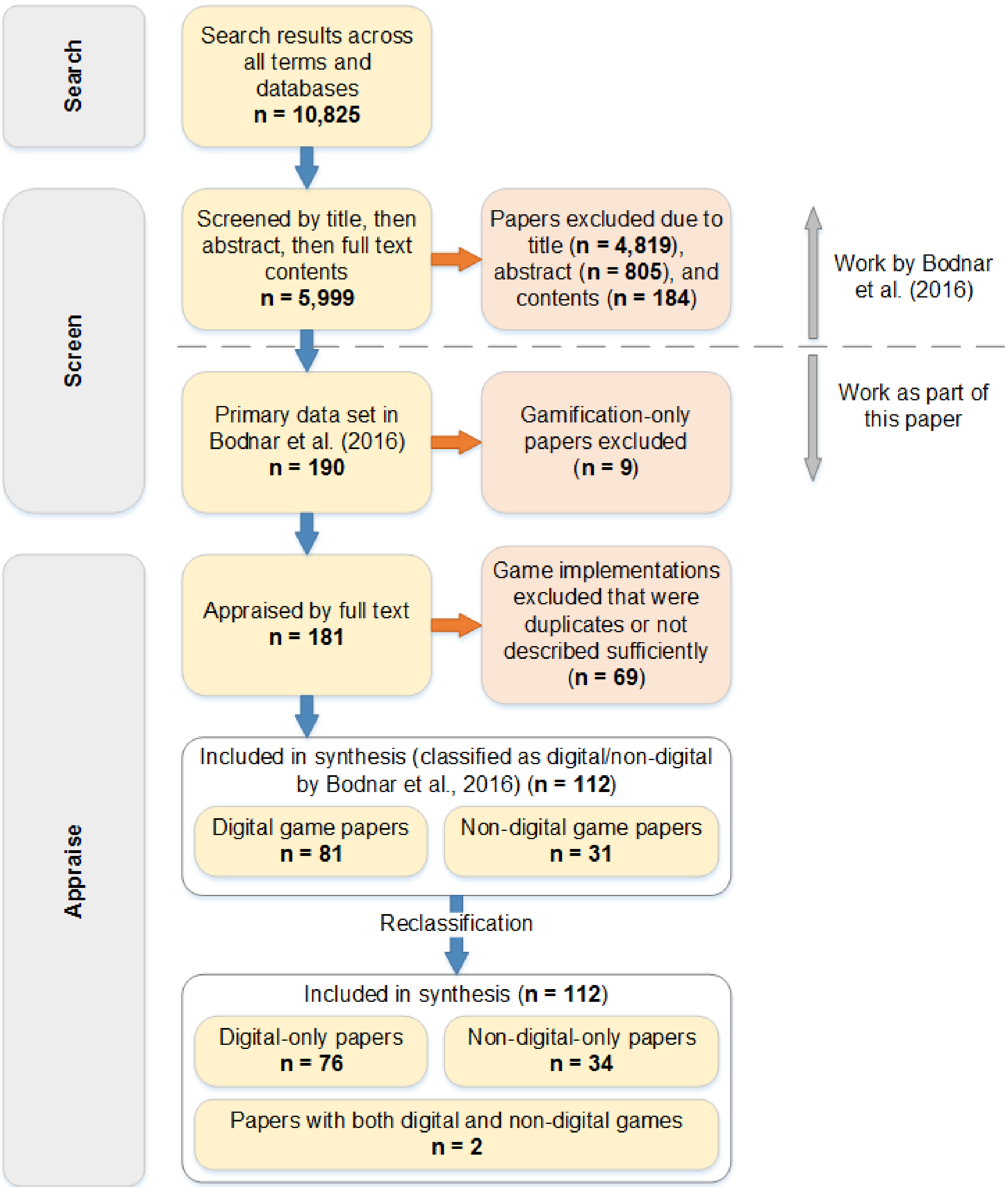

Figure 1: Process of filtering dataset to papers included in synthesis. Graphic adapted from Borrego et al. (2014).

To answer our second research question, we then used a priori coding to categorize each game as a replacement, amplification, or transformation of typical active learning activities in engineering classrooms, in accordance with the RAT framework. We considered a "typical" active learning activity as any non-lecture activity that is commonplace in engineering curricula, the most prominent being quizzes, mathematical problems, engineering design projects, lab exercises, and programming tasks. Games were considered "transformations" if they offered learning tasks that diverged from these common practices, and "amplifications" if they offered similar learning tasks with enhanced features not feasible without the game. Otherwise, games were classified as "replacements." Like the PLC codes, we presented the RAT codes according to the frequency of their appearance in the papers we analyzed.

To bolster the research quality of our qualitative analysis, we utilized strategies outlined by Anfara et al. (2002). To ensure the credibility of our findings, we conducted peer debriefing within the research team to ensure that our conclusions made sense given the results of our investigation. To improve the dependability of our code definitions, we conducted researcher triangulation through an intercoder reliability check. We provided our list of PLC and RAT codes and their definitions, along with a sampling of 10 papers, to a qualitative researcher outside the research team. The sampling of papers covered all six common PLC codes and all three RAT classifications. The external researcher applied the codes she reasoned appropriate based on their definitions, and we met with her to compare results. In the case of disagreement, we revised our definitions until everyone agreed on the proper application of each code.

Results and Discussion

Looking across digital and non-digital games, we found a handful of interesting trends for both PLC and RAT frequencies. We found that all six of our common PLC codes were present in both digital and non-digital game implementations, but remarkably different frequencies, speaking to the different strengths of the two mediums. We found a similar trend with RAT classifications, with digital games more commonly featuring amplifications and non-digital games featuring a higher proportion of transformations. Finally, we observed that most PLCs could be described as fitting within a particular RAT classification. The appendix presents a table summarizing our results for each included paper. The remainder of this section will discuss our findings in greater depth.

Primary Learning Contributions

Table 1 outlines the six most common primary learning contributions we found among the games we analyzed, along with examples of games with each contribution. Overall, we found substantial variation in ways games could contribute to learning in engineering education. Some games sought to provide more engaging alternatives to common classroom activities, either by making things like quizzes or assignments more like games, or by providing a fictional context for solving engineering problems. Other games offered students opportunities to develop engineering skills by giving them systems that allowed for repeated practice and feedback loops, or to expose students to engineering work through microcosmic simulations. The remaining games aimed to help students understand and interpret engineering ideas, such as by engaging in experiences analogous to engineering situations, or by applying a skill or concept in intuitive ways.

Table 1: Definitions and examples for primary learning contribution codes

Primary learning contribution code	**Definition**	**Example**
Application of concepts/skills	Students apply one or more engineering concepts or skills in an activity to “see them in action” in a more intuitive or hands-on context.	A semester-long investment game in which students made engineering-economics-related decisions each week and saw how their decisions had a long-term impact on economic performance of their fictional companies (Dahm, 2002).
Analogical activity	Students engage in learning tasks not directly representative of engineering work or concepts, but similar enough that useful comparisons are drawn. Necessitates some form of debrief or reflection.	A board game where students worked together to place game pieces to build a building, and then the building collapsed and the team had to come to an agreement whose fault the collapse was. Followed by a debrief on the social difficulties associated with ethics-related engineering disasters (Lloyd & van de Poel, 2008).
Feedback-practice loop	Students practice the application of concepts or skills, get feedback about performance, and then practice more. The goal is to improve performance in particular concepts/skills over time.	A digital game that gave students skeleton code, asked students fill in the rest of the code, gave students visual and textual feedback about the code’s results, and allowed students to retry or move to a harder level (Chaffin et al., 2009).
Gamified academic activity	Students perform common classroom learning task(s) with task-irrelevant game mechanics (e.g., points, rewards, moving around a board) attached to them.	A board game where students answered multiple-choice questions about the learning content to correctly to move around the board (Bekir et al., 2001).
Fictional Context	Students solve engineering problems within a fictional context, which is sometimes supported by virtual environments. Many games contained fictions, but only games whose authors emphasized the fictional context as being highly relevant to learning tasks were coded with this PLC.	A company-themed website in which design-related information and documents were exchanged between students and a fictitious manager (Brumm et al., 2004).
Microcosm	Students engage in a simulation meant to familiarize them with real engineering work or train them to conduct real engineering work, albeit on a smaller scale than a real engineering project.	A simulation in which students played different roles in an open-source software development project and were responsible for fixing bugs, implementing new features, and developing forked programs. The goal of game was to give students a hands-on example of what open-source development is like (Kilamo, 2010).

There were some other primary learning contributions we identified that were only used by one or two games each. These included metacognitive aids for solving engineering problems, using a virtual world as an online classroom, using a game as a classroom demonstration of programming concepts, and offering opportunities to creatively interpret engineering concepts and communicate them in unconventional ways. For brevity, we grouped these less common PLCs into an "other" category, and we will not discuss them further.

Table 2 shows the frequency of each primary learning contribution among digital and non-digital game publications. The most common PLC was application of concepts/skills, followed by analogical activity, feedback-practice loop, and gamified academic activity. Fictional context and microcosm appeared at a lower frequency. We found some similarities in PLC presence across digital and non-digital games. Application of concepts/skills was a popular PLC in both digital and non-digital game implementations, indicating that both digital and non-digital games can lend themselves well to seeing engineering concepts applied in intuitive ways. Gamified learning activities were also common across both types of games, indicating that both work well as a way to adapt common learning tasks with game elements.

We also found several differences between the PLCs present in digital and non-digital games. Feedback-practice loops were abundant in digital games but rare in non-digital ones, which attests to the strength of digital games in being able to provide the instantaneous feedback necessary to establish a responsive feedback-practice loop. Similarly, fictional contexts and microcosms were more common in digital games than non-digital games. This difference can likely be attributed to the tools available on computers to craft the virtual spaces (simulations, customized LMS interfaces, virtual worlds) that were often used to support these two PLCs. On the other hand, analogical activities were far more prevalent in non-digital games than digital games, which attests to the strength of non-digital games to allow instructors to quickly and cheaply develop scenarios that can be used as analogies during class debrief discussions and/or student reflection.

Table 2: Frequency of publications featuring games with each primary learning contribution. Percentages indicate the fraction of total publications in each category (digital, non-digital, combined)—i.e., percentage of column total.

Primary Learning Contribution (PLC)	**Publications featuring games with PLC**		***Combined (Digital + Non-Digital) Publications with PLC***
	Digital Games	**Non-Digital Games**	
Application of concepts/skills	22 (28%)	13 (36%)	*35 (31%)*
Analogical activity	10 (13%)	16 (44%)	*26 (23%)*
Feedback-practice loop	22 (28%)	2 (6%)	*24 (21%)*
Gamified academic activity	15 (19%)	8 (22%)	*23 (21%)*
Fictional Context	8 (10%)	1 (3%)	*9 (8%)*
Microcosm	7 (9%)	1 (3%)	*8 (7%)*
Other	5 (6%)	1 (3%)	*6 (5%)*
Total (All PLCs)	*78 (100%)*	*36 (100%)*	*112 (100%)*

RAT Classifications

Table 3 outlines the frequency of RAT classification among digital and non-digital game publications. For both digital and non-digital games, the majority of games were transformative in nature, enabling new kinds of learning tasks beyond traditional engineering active learning activities. Interestingly, while transformations comprised a narrow majority of digital games (55%), they comprised 75% of non-digital games. We were surprised to find that transformations of the learning process—often acclaimed as a theoretical advantage of digital games (e.g., Gee, 2003; Plass et al., 2015; Shaffer, 2006)—were more prominent in non-digital games than digital games. On the other hand, non-digital games featured few amplifications, while amplifications were abundant in digital games. This result was expected, as many of the enhancements to common learning tasks endemic to amplification—e.g., automation of calculation and assessment, contextual help systems—are easily accomplished by computers.

Table 3: Frequency of publications with games classified under each RAT classification. Percentages indicate the fraction of total publications in each category (digital, non-digital, combined)—i.e., percentage of column total.

RAT Classification	**Publications including games with RAT classification**		***Combined (Digital + Non-Digital) Publications with RAT classification***
	Digital Games	**Non-Digital Games**	
Replacement	13 (17%)	8 (22%)	*21 (19%)*
Amplification	25 (32%)	1 (3%)	*26 (23%)*
Transformation	44 (56%)	27 (75%)	*71 (63%)*
Total (All classifications)	*78 (100%)*	*36 (100%)*	*112 (100%)*

While we considered RAT classification as a property of the game itself—and not a property of the game's PLCs—we found that most PLCs tended to be associated with a particular RAT classification. Table 4 summarizes this relationship. We found that, with a handful of exceptions, games that sought to gamify typical academic activities acted as replacements for typical engineering active learning activities, adding potentially engaging elements without amplifying or transforming the learning process. Amplification of the learning process was most prevalent in digital games that took advantage of the ability to give instantaneous feedback in contributing practice-feedback loops for learning skills. Transformation of the learning process occurred most prominently in games that aimed to help students better understand or apply engineering ideas and work, including analogical activities, applications of concepts/skills, and microcosmic simulations. Fictional context was the only PLC in which a majority of games did not fall within a particular RAT classification, primarily because the transformative potential of a fictional context lay in the kinds of engineering problems it enables students to solve. Simple narratives might act as replacements by adding flair to typical engineering design projects (e.g., Butler, 2013), while a fictional context supported by a virtual world with interactable non-player characters may enable a transformative office simulation not feasible in a normal classroom (e.g., Connolly et al., 2007).

Table 4: Frequency with which games fell within each RAT classification for a given primary learning contribution. Bolded numbers indicate the RAT classification(s) in which the majority of games with each PLC were classified.

Primary Learning Contribution (PLC)	**RAT Classification of Game with PLC**		
	Replacement	**Amplification**	**Transformation**
Application of concepts/skills	1	2	**32**
Analogical activity	**--**	**--**	**26**
Feedback-practice loop	2	**12**	10
Gamified academic activity	**16**	7	--
Fictional Context	**2**	**3**	**4**
Microcosm	**--**	**--**	**8**
Other	1	4	1

Implications for Research and Instruction

In GBL research, several recent systematic reviews and meta-analyses have attempted to identify the learning benefits of games in aggregate (Bodnar et al., 2016; Clark et al., 2016; Wouters et al., 2013). However, as we have demonstrated, games can contribute to learning processes in diverse ways, and thus instructors with different learning objectives will likely select or design games that lend themselves well to compatible PLCs. As literature increasingly calls for more nuanced investigations of the benefits of GBL beyond simple media comparison studies (Clark et al., 2016; Mayer, 2014; Young et al., 2012), the learning objectives and related learning contributions of each game application may be important variables to consider in future research. Particularly, reviews looking to aggregate results across game-based learning studies may find more meaningful conclusions when using these variables to mediate their generalizations.

For GBL instruction, because games can contribute to learning in different ways, different games will likely require different kinds of instructor input. For example, an instructor using a game as a practice-feedback loop may find themselves primarily helping students understand the value of the game and assisting students if they get stuck—much of the learning happens through gameplay. On the other hand, an instructor using a game as an analogical experience may be more inclined to help students understand how the game is played and debrief extensively to ensure that students connect the experience to appropriate curricular goals. This implication for practice is consistent with a growing body of literature suggesting that instructors play an important role in helping to set up, scaffold, debrief, and evaluate game activities (Abdul Jabbar & Felicia, 2015; Hanghøj & Brund, 2011; Hays, 2005; Kangas et al., 2016). Future research and practice recommendations may benefits from exploring how instructional practice changes in accordance with a game's primary learning contributions.

As a final implication for practice, we found that non-digital games more commonly featured transformative contributions to learning than digital games. In a recent publication, Jamieson and Grace (2016) called for researchers and instructors to consider whether the learning benefits from games justified the cost of their creation, and to pay particular attention to how much a prospective game would transform learning. Given that non-digital games for learning require far fewer resources to create than digital games (Institute of Play, 2014), and given our finding that non-digital games have abundantly led to transformative learning contributions, instructors may wish to foreground non-digital games when considering GBL activities.

Limitations

While our analysis yielded interesting results, a few limitations should be noted. First, because this is a secondary analysis of a published systematic review with a date range ending in 2014, any relevant publications in the proceeding years (2015-2018) were not captured.) This limitation is assuaged by the fact that we found all six of our primary learning contribution codes outside the “other” category after reviewing approximately 70% of our data, with no new codes being added in the last 30%. Therefore, we would not expect a review of more papers to generate many new codes. We found the resources saved by performing a secondary analysis of an existing data set to outweigh the costs of working with a slightly outdated collection of publications. We would encourage other researchers to replicate our methodological approach to expand the usefulness of other systematic reviews, recognizing that the recency of Bodnar et al. (2016) and the openness of their inclusion criteria enabled our approach.

Second, the RAT framework we selected for our analysis only catalogues the extent to which a game transforms the learning process, not how beneficial that transformation is. Introducing new kinds of learning tasks does not guarantee those learning tasks will result in benefits to learning. That said, calls to improve engineering education hinge on the notion that engineering curricula should better prepare students for real engineering work (Jamieson & Lohmann, 2009; The National Academy of Engineering, 2005), and exposure to different aspects of real engineering work was a common feature of PLCs that tended by transformative—particularly analogical activities and microcosms.

Conclusion

Research into game-based learning has attempted to identify the learning benefits of games in aggregate, treating game-based learning as a single, unifiable pedagogy. However, as we have demonstrated in this paper, different games contribute to learning in several distinct ways, and some transform learning experiences more than others. We identified six primary learning contributions that describe the main ways different games affect learning processes, and catalog the extent to which these games transform learning tasks. Understanding these primary learning contributions and including them as variables could provide more nuanced and meaningful ways to generalize game-based learning findings and guide game-based instructional practice.

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Appendix: Summary of Findings by Paper

Included Paper	Medium of Game(s)	PLCs of Game(s)	RAT Classification of Game(s)
Andrianoff and Levine (2002)	Non-Digital	Analogical Activity	Transformation
Arastoopour et al. (2012)	Digital	Fictional Context	Amplification
Baker et al. (2005)	Non-Digital	Analogical Activity	Transformation
Bartolomei (2002)	Non-Digital	Gamified Academic Activity	Amplification
Battisti et al. (2011)	Digital	Application of Concepts/Skills	Transformation
Bauer and Adams (2005)	Non-Digital	Gamified Academic Activity	Replacement
Bekir et al. (2001)	Non-Digital	Gamified Academic Activity	Replacement
Brannon et al. (2014)	Non-Digital	Application of Concepts/Skills	Transformation
Brinkman (2009)	Non-Digital	Analogical Activity	Transformation
Brumm et al. (2004)	Digital	Fictional Context	Transformation
Butler (2013)	Digital	Fictional Context	Replacement
Butler-Purry et al. (2009)	Digital	Feedback-Practice Loop	Transformation
Byerley (2001)	Non-Digital	Gamified Academic Activity	Replacement
Callaghan and Cullen (2014)	Digital	Feedback-Practice Loop	Amplification
Callaghan et al. (2010)	Digital	Gamified Academic Activity, Other	Replacement, Amplification
Carpick (2002)	Non-Digital	Gamified Academic Activity	Replacement
Cetin (2012)	Digital	Gamified Academic Activity	Replacement
Chaffin et al. (2009)	Digital	Feedback-Practice Loop	Amplification
Chang et al. (2010)	Digital	Analogical Activity	Transformation
Chang et al. (2011)	Digital	Feedback-Practice Loop	Replacement
Chen et al. (2014)	Digital	Feedback-Practice Loop	Amplification
Coller (2007)	Digital	Feedback-Practice Loop, Fictional Context	Amplification
Connolly et al. (2007)	Digital	Fictional Context	Transformation
Crown (2001)	Digital	Feedback-Practice Loop	Amplification
Dahm (2002)	Digital & Non-Digital	Application of Concepts/Skills	Transformation
Darling et al. (2008)	Digital	Application of Concepts/Skills	Transformation
Delarue et al. (2011)	Digital	Analogical Activity	Transformation
Dib and Adamo-Villani (2014)	Digital	Feedback-Practice Loop	Transformation
Eagle and Barnes (2009)	Digital	Analogical Activity, Feedback-Practice Loop	Amplification, Transformation
Ebner and Holzinger (2007)	Digital	Gamified Academic Activity	Replacement
Fernández-Samacá and Ramírez (2011)	Non-Digital	Analogical Activity	Transformation

Included Paper	**Medium of Game(s)**	**PLCs of Game(s)**	**RAT Classification of Game(s)**
Foss and Eikaas (2006)	Digital	Application of Concepts/Skills	Transformation
Fuentes and Crown (2007)	Digital	Feedback-Practice Loop	Amplification
Ghatala et al. (2009)	Non-Digital	Application of Concepts/Skills	Transformation
González-Tablas et al. (2013)	Digital	Gamified Academic Activity	Replacement
Gouveia et al. (2011)	Digital	Application of Concepts/Skills	Transformation
Grau et al. (2012)	Non-Digital	Analogical Activity, Application of Concepts/Skills	Transformation
Grecu et al. (2013)	Non-Digital	Other	Transformation
Guardiola et al. (2011)	Digital	Application of Concepts/Skills	Transformation
Hartman and Galati (2000)	Digital	Application of Concepts/Skills	Transformation
Hauge and Riedel (2012)	Digital	Microcosm	Transformation
Hulme et al. (2009)	Digital	Application of Concepts/Skills	Transformation
Idowu (2008)	Non-Digital	Gamified Academic Activity	Replacement
Isaacs et al. (2008)	Digital	Application of Concepts/Skills	Transformation
Jalkio and Schupp (2011)	Non-Digital	Analogical Activity	Transformation
Karel et al. (2013)	Digital	Other	Amplification
Kasaraneni et al. (2009)	Digital	Application of Concepts/Skills	Transformation
Kilamo (2010)	Digital	Microcosm	Transformation
Kuk et al. (2012)	Digital	Gamified Academic Activity	Amplification
Lau et al. (2013)	Non-Digital	Analogical Activity	Transformation
Lee et al. (2013)	Digital	Feedback-Practice Loop	Amplification
Lloyd and van de Poel (2008)	Non-Digital	Analogical Activity	Transformation
Long et al. (2009)	Digital	Analogical Activity	Transformation
Pyykkö et al. (2006)	Digital	Microcosm	Transformation
Martin-Dorta et al. (2013)	Digital	Gamified Academic Activity	Amplification
Mehta et al. (2013)	Digital	Feedback-Practice Loop	Transformation
Minerick (2010)	Non-Digital	Gamified Academic Activity	Replacement
Moreno (2012)	Digital	Application of Concepts/Skills, Feedback-Practice Loop	Transformation
Munz et al. (2007)	Digital	Application of Concepts/Skills	Amplification
Musselman (2001)	Non-Digital	Application of Concepts/Skills	Transformation
Natvig and Line (2004)	Digital	Gamified Academic Activity	Amplification
Navarro and Hoek (2007)	Digital	Application of Concepts/Skills	Transformation
Ncube (2007)	Digital	Application of Concepts/Skills	Transformation
O'Brien and Sirokman (2014)	Non-Digital	Application of Concepts/Skills, Feedback-Practice Loop	Transformation
Orbey et al. (2014)	Digital	Gamified Academic Activity	Amplification
Ozelkan and Galambosi (2007)	Non-Digital	Application of Concepts/Skills	Transformation

Included Paper	**Medium of Game(s)**	**PLCs of Game(s)**	**RAT Classification of Game(s)**
Park (2012)	Non-Digital	Application of Concepts/Skills, Fictional Context	Transformation
Pfotenhauer et al. (2009)	Digital	Feedback-Practice Loop	Transformation
Philpot et al. (2003)	Digital	Feedback-Practice Loop	Transformation
Philpot et al. (2005)	Digital	Feedback-Practice Loop	Transformation
Popyack (2009)	Digital	Gamified Academic Activity	Replacement
Pötter et al. (2014)	Digital	Feedback-Practice Loop, Microcosm	Amplification, Transformation
Pozzi et al. (2014)	Non-Digital	Application of Concepts/Skills, Feedback-Practice Loop, Microcosm	Transformation
Qualters et al. (2006)	Non-Digital	Application of Concepts/Skills	Transformation
Rajan et al. (2013)	Digital	Application of Concepts/Skills	Transformation
Ranalli and Ritzko (2013)	Digital	Analogical Activity	Transformation
Reise et al. (2014)	Non-Digital	Analogical Activity	Transformation
Remeikas et al. (2010)	Digital	Application of Concepts/Skills, Gamified Academic Activity	Amplification, Transformation
Rivera et al. (2012)	Digital	Analogical Activity, Application of Concepts/Skills	Transformation
Rusu, Russell, Burns, et al. (2011)	Digital	Analogical Activity	Transformation
Rusu, Russell, Cocco, et al. (2011)	Digital	Analogical Activity	Transformation
Sancho and Fernández-Manjón (2010)	Digital	Fictional Context	Amplification
Santana and Masini (2005)	Non-Digital	Analogical Activity	Transformation
Seager et al. (2010)	Non-Digital	Analogical Activity	Transformation
Serrano-Laguna and Fernández-Manjón (2014)	Digital	Feedback-Practice Loop	Amplification
Shahbazi and Shahbazmohamadi (2013)	Non-Digital	Gamified Academic Activity	Replacement
She et al. (2013)	Digital	Gamified Academic Activity	Replacement
Sherif and Mekkawi (2010)	Digital	Microcosm	Transformation
Son et al. (2011)	Digital	Feedback-Practice Loop, Microcosm	Transformation
Spierre et al. (2012)	Digital & Non-Digital	Analogical Activity	Transformation
Strawderman (2009)	Digital	Analogical Activity, Application of Concepts/Skills	Transformation
Su and Cheng (2013)	Digital	Gamified Academic Activity	Replacement
Tang et al. (2011)	Digital	Other	Amplification
Tang et al. (2012)	Digital	Application of Concepts/Skills, Other	Amplification

Included Paper	**Medium of Game(s)**	**PLCs of Game(s)**	**RAT Classification of Game(s)**
Taran (2007)	Non-Digital	Analogical Activity	Transformation
Turtiainen et al. (2002)	Digital	Microcosm	Transformation
Venter and Coetzee (2014)	Digital	Application of Concepts/Skills	Transformation
Verzat et al. (2009)	Non-Digital	Analogical Activity	Transformation
von Wangenheim et al. (2012)	Non-Digital	Analogical Activity	Transformation
Wang (2004)	Non-Digital	Analogical Activity	Transformation
Wang et al. (2010)	Non-Digital	Application of Concepts/Skills	Transformation
Wang and Zhu (2009)	Digital	Application of Concepts/Skills	Transformation
Wang and Tseng (2010)	Digital	Feedback-Practice Loop, Gamified Academic Activity	Replacement
Wu et al. (2008)	Digital	Fictional Context	Replacement
Wu et al. (2011)	Digital	Gamified Academic Activity	Replacement
Yang et al. (2012)	Digital	Feedback-Practice Loop	Amplification
Ye et al. (2007)	Digital	Other	Replacement
Zhang et al. (2013)	Digital	Feedback-Practice Loop	Amplification
Zheleva et al. (2002)	Digital	Fictional Context	Transformation
Zhu et al. (2014)	Digital	Gamified Academic Activity	Amplification
Zualkernan et al. (2012)	Digital	Application of Concepts/Skills	Transformation
Zuppiroli et al. (2012)	Non-Digital	Application of Concepts/Skills	Replacement