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An Investigation of the Interrelationships between Motivation, Engagement, and Complex Problem Solving in Game-based Learning

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ABSTRACT

Digital game-based learning, especially massively multiplayer online games, has been touted for its potential to promote student motivation and complex problem-solving competency development. However, current evidence is limited to anecdotal studies. The purpose of this empirical investigation is to examine the complex interplay between learners' motivation, engagement, and complex problem-solving outcomes during game-based learning. A theoretical model is offered that explicates the dynamic interrelationships among learners' problem representation, motivation (i.e., interest, competence, autonomy, relatedness, self-determination, and self-efficacy), and engagement. Findings of this study suggest that learners' motivation determine their engagement during gameplay, which in turn determines their development of complex problem-solving competencies. Findings also suggest that learner's motivation, engagement, and problem-solving performance are greatly impacted by the nature and the design of game tasks. The implications of this study are discussed in detail for designing effective game-based learning environments to facilitate learner engagement and complex problem-solving competencies.

Keywords

Complex problem solving, Motivation, Engagement, Massively multiplayer online games, Game-based learning, Educational game design

Introduction

Proponents have argued that massively multiplayer online games (MMOGs) possess unique affordances to address complex problem-solving skill development that our current educational system is failing to provide (e.g., OECD, 2004) by drawing on a powerful pedagogy: *situated learning*. It has also been argued that game-based situated learning environments promote student motivation and engagement (e.g., Gee, 2007; Greenfield, 2010). Unfortunately, very few researchers began to move the discussion of complex problem solving beyond descriptive research; the majority of current discourse in the field can be summed up as "games are problems being solved by players [and games are engaging]; therefore, playing games will help [and motivate] people be better problem solvers" (Hung & van Eck, 2010, p. 228). However, this is not sufficient to guide our development of educational games to directly address complex problem solving and student motivation as learning outcomes. In the context of game-based learning, the relationships among problem solving, motivation, and engagement are far more complex than they appear at first.

We argue that complex problem solving and associated cognitive processing and motivational requirements are most impacted by gameplay; and that interactivity captures the most salient features of gameplay as it relates to complex problem solving and motivation. Hence, the purpose of this study was to investigate the interrelationships among complex problem solving, motivation, and engagement in the context of game-based learning and offer an empirically-validated framework that can guide future studies and instructional design efforts.

MMOGs as complex and ill-structured problem-solving environments

It has been argued convincingly that games serve as situated problem-solving environments, in which players are immersed in a culture and way of thinking (Dede, 2009; Gee, 2007). This is especially true for massively multiplayer online games, which are situated in complex and ill-structured problems. For instance, in the *McLarin's Adventures* MMOG that served as the testbed for this study, students play the role of researchers who were sent on a mission to explore the habitability of earth-like planets outside of our solar system. The problem is ill-structured because both the given state and the desired goal state are not clearly defined. The desired goal state is vaguely defined as finding a planet, on which a settlement area can be built for the humans so that this planet can serve as a colony for the people of the earth. In the first game narrative, the players detect a planet, on which atmospheric conditions (i.e., O_2 and CO_2 levels) allow for humans to breathe comfortably. When they land on the planet, the players can infer from the visibly-apparent characteristics of the surface that the planet resembles a tropical island on the earth.

This problem is also very complex due to the large number of highly inter-connected variables affecting the problem state. This means that changes in one variable affect the status of many other related variables; therefore, it is very difficult to anticipate all possible consequences of any action. Furthermore, not all of the variables may lend themselves to direct observation. Often, knowledge about the symptoms is available, from which one has to infer the underlying state. Dealing with intransparency of the problem variables and the interrelationships among them is often difficult due to time-delayed effects; not every action shows immediate consequences. Hence, complex problem-solving situations often change decremental or worsen, forcing a problem solver to act immediately, under considerable time pressure. Therefore, complex problem-solving situations bear multiple goals, some of which could be contradictory requiring a reasonable trade-off. All of these factors make complex ill-structured problem solving very challenging (Funke, 1991). In the *McLarin's Adventures* MMOG, players deal with large number of dynamically interconnected variables while they are researching environmental conditions, planning and building the settlement, including planning for sustainable water and food resources, shelters, and so on. Cut scenarios in the game present unforeseen challenges to the players, which change the problem state dynamically, forcing the players to act immediately under pressure.

Eseryel (2006) found that problem understanding and problem solution are not two separate activities in complex, ill-structured problem-solving. Rather, they are intimately connected; they complete each other and develop in parallel. As the solvers try to understand the problem in its entirety by constructing appropriate mental representation to model and comprehend the dynamic interrelationship among problem variables they understand how a change in one variable may affect another, thereby, could mentally simulate in their *mind's eye* (Seel, 2001, p. 407) the dynamic problem system in its entirety imagining the events that would take place if a particular action were to be performed. In this way, mental simulation of the solver's problem space supports causal reasoning during gameplay, allowing one to perform entire actions internally, to judge and interpret the consequences of actions, and to draw appropriate conclusions.

During complex, ill-structured problem solving, it is likely that the solvers either would not possess existing schema of the problem domain or their schema would have to undergo accretion, tuning, or reorganization (Rumelhart & Norman, 1978) to accommodate newly acquired information. The accommodation process is supported by mental models, which are dynamic ad hoc representations of reality to help the individual understand or simplify a phenomenon (Ifenthaler & Eseryel, 2013).

Hence, during complex ill-structured problem solving, solver's problem representation elicited as a causal representation can serve as a basis for assessing his or her cognitive structure and problem-solving performance (Eseryel, 2006). An individual's cognitive structure is made up of various schemata and mental models that can be embedded within one another within a hierarchy, which is used to develop procedural knowledge for problem solving purposes within a specific domain (Tennyson & Cocchiarella, 1986). In a recent study, Eseryel, Ifenthaler, and Ge (2013) showed the validity and reliability of the assessment method based on causal representations in the context of complex, ill-structured problem solving during game-based learning. When compared to that of a novice, a domain expert's cognitive structure is considered to be more tightly integrated and has a greater number of linkages among interrelated concepts. There is thus immense interest on the part of researchers to assess a novice's cognitive structure and compare it with an expert's in order to identify the most appropriate ways to bridge the gap to increase problem-solving performance.

Despite the importance of cognitive structure for comprehension, integration of new information, and the ability to solve complex, ill-structured problems (Jonassen, Beissner, & Yacci, 1993), a focus solely on players' cognitive structures is incomplete. Another important prerequisite for successful problem-solving performance during game-based learning is suggested by research on motivational aspects of cognition (e.g., Weiner, 1986), specifically the problem solver's motivation (Mayer, 1998).

This approach suggests that if game-based learning environments can maintain and enhance players motivation, despite the challenges associated with complex, ill-structured problem solving, the players would engage longer in gameplay, complete more tasks, which, in turn, will contribute to the sense of competence (Ryan & Deci, 2000; Ryan, Rigby, & Przybylski, 2006). Hence, the longer players are engaged with the game the more their representations of the complex problem scenario of the game resemble to the *expert* problem representation underlying the game narrative; thereby improving their complex problem-solving performance.

Motivation and digital game-based learning

Based on the self-determination theory, the nature and quality of motivation are determined by satisfying three basic needs: *autonomy*, *competence,* and *relatedness* (Ryan & Deci, 2000). Satisfaction of these needs fosters internalized forms of motivation, such as intrinsic motivation (interest), which would lead to higher quality engagement and learning (Ryan & Deci, 2000). Another related key factor that drives motivation and engagement is self-efficacy (Bandura, 1997), which concerns one's perceived capability for achieving desired outcomes. These key components of motivation are further elaborated in the context of digital game-based learning environments in the following paragraphs.

Autonomy, competence, and *relatedness* are key elements to sustain and maintain one's motivation (Ryan & Deci, 2000). Autonomy refers to "regulating one's own behavior and experience and governing the initiation and direction of action" (Ryan & Powelson, 1991, p. 52). For educational MMOGs to be motivating, students should be provided with the *paradox of control* in an uncertain situation (Csikszentmihalyi, 1990, p. 58). Hence, learners have a sense of control over the environment. Additionally, game-based learning environments should provide learners with opportunities for autonomous choices. In the game-based learning environment, any constrains may limit true choices, which in turn have negative effects on learners' perceived autonomy.

In addition to satisfying the need for autonomy, self-determined motivation requires that individuals develop a "sense of accomplishment and effectance" (Ryan & Powelson, 1991, p. 52, p.52). Within a game environment, game-players need to believe that they are moving closer to the intended outcome of the game. The challenges they face should match their developed skills so that they can experience attainable challenges, but with some uncertainty of outcomes (Csikszentmihalyi, 1990). Feedback mechanisms within the game are crucial for developing a sense of competence because they will inform learners if they are progressing towards the goal (Csikszentmihalyi, 1990; Fullerton, Swain, & Hoffman, 2004). A number of factors may promote or hinder learners' perceived competence, including difficulty of tasks and usability of a game (e.g., user interface and navigation features).

Self-efficacy is one's belief on his/her ability to achieve a desired outcome (Bandura, 1997), which has been found to be a good predictor of future learning outcomes (Pajares, 1996). Some factors influencing self-efficacy include performance feedback and social comparison (Bandura, 1993). When people attain their goals, self-efficacy can be increased. People also judge their own ability for a task by observing how other people perform in attaining their goals. In an MMOG environment, players may gain self-efficacy through overcoming various challenges in a game. However, they may lose self-efficacy as they observe other players struggle in the game. When game players have high self-efficacy, they are more likely to put forth effort and be more persistent in pursuing their problem-solving tasks (Zimmerman & Campillo, 2003). In short, when their self-efficacy for challenges of the game is higher, players are more likely to engage in the game.

Finally, self-determination theory stresses the importance of building positive interpersonal relationships in self-determined motivation (Ryan & Deci, 2000). Traditionally, *relatedness* refers to students' feeling of belonging in the classrooms, such as acceptance, inclusion, and support. It can also be referred to the quality of the relationship between students and teachers (Reeve, 2006). In a game-based learning environment, relatedness can be extended to the quality of relationships among the players (Ryan, et al., 2006). As players establish a common language and work towards common goals, peer relationships can be strengthened. Hence, a game-based learning environment may foster relatedness as students are engaged in solving complex problems together.

Motivational theories can explain students' behaviors in a learning environment, such as effort and persistence (e.g. Ryan & Deci, 2000), which are important indicators of *engagement*. Effort and persistence are directly influenced by the combined motivational factors, such as interest, autonomy, competence, relatedness, and self-efficacy. These motivational factors influence students' regulation effort and reflection on their understanding of the problem and the quality of solutions (Pintrich, 2000). In a game-based learning environment, effort and persistence can be operationalized through the amount of time a player spends in a task and the number of tasks that a player accomplishes within a limited time period. In light of our observations of digital game-based learning, problem solving, and motivation, we assume that an in-depth investigation of these complex processes will help instructional designers to understand the relationship between complex problem solving, motivation and engagement and to improve the design of educational games that are most appropriate for learning and problem solving within digital game-based learning environment.

Purpose of the study

Figure 1 depicts the theoretical model stemmed from the literature and represents the influence of motivation and prior problem representation on student engagement, which in turn influences students' complex problem-solving performance in game-based learning, indicated by their problem representation. The model utilizes self-determination theory and self-efficacy theory (Bandura, 1997; Ryan & Deci, 2000), as well as cognitive structure and problem representation (Ifenthaler & Seel, 2011; Jonassen et al., 1993), as theoretical foundations. Our research model hypothesizes that students' problem representation can be explained by the interactions among problem representation, factors of motivation, and task.

Specifically, we assumed that the degree of *interest* (a reflection of intrinsic motivation) during gameplay has a positive effect on students' *engagement* (the number of tasks accomplished and time spent playing the game) in the complex problem scenario (Hypothesis 1a). Further, the model identifies a positive influence of the student's *perceived competence* during gameplay on his/her *engagement* (Hypothesis 1b). Additionally, we assume that the perceived *autonomy* during gameplay has a positive effect on students' *engagement* (Hypothesis 1c). Also, the experienced *relatedness* during gameplay has a positive effect on his/her *engagement* (Hypothesis 1d). Finally, we assume that degree of *self-efficacy for the tasks* during the game has a positive effect on students' *engagement* (Hypothesis 1e). Overall, we assume that students' *engagement* and *prior problem representation* have a positive effect on his/her *problem representation* (Hypothesis 2).

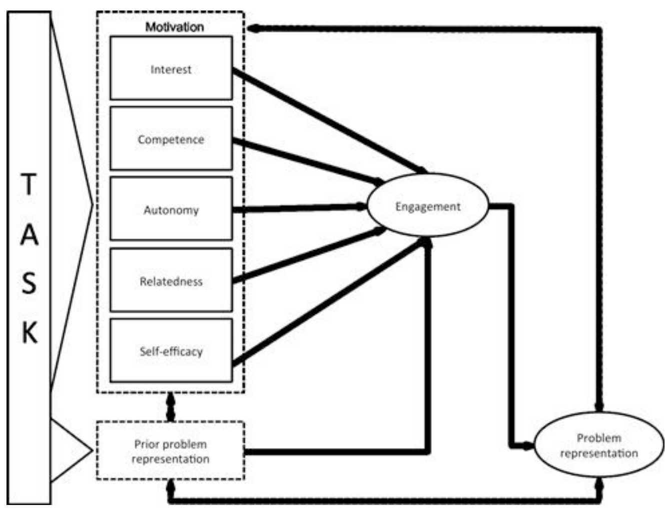

Figure 1. Influence of motivation and cognitive structure on problem representation (rectangular shapes depict initial influences variables; oval shapes depict outcome variables; single arrows depict one-way causal relationship in the direct of the arrow, whereas bi-arrows depict two-way causal relationships)

Method

Participants

A rural high school in the Midwest of the United States was used as a testbed for this experimental study. All of the ninth-grade students in the school (ten classrooms) took part in our study. The data reported here were from $N = 88$ students (50 female and 38 male) from whom we received both parental consent and student assent forms. Their average age was 14.6 years (*SD* = .7). All of the participants played the game on a frequent basis (at least twice a week).

Materials

***McLarin's Adventures*.** *McLarin's Adventures* is a massively multiplayer online game (MMOG) designed for 8th and the 9th grade students. In this MMOG students are asked to play the role of researchers set in a survivor story where they explore an uninhabited, uncharted island on a distant earth-like planet. The goal of the game is to successfully colonize a planet and become the winning team.

***Complex problem scenario*.** The pre- and posttest was identical and involved a near-transfer problem-solving task when compared with the complex problem scenario in the *McLarin's Adventures* MMOG. Students were asked to play the role of researchers tasked with developing a successful settlement area on a newly found planet, where humans could survive. They were prompted to think what humans needed to survive and were asked to make a list of each of these factors. The solution to the complex problem scenario was represented in the form of an annotated causal representation, which served as the *problem representation* construct.

***Motivation inventory*.** The motivation inventory consisted of the following subscales. Four subscales of the Intrinsic Motivation Inventory (Ryan & Deci, 2000) were used to assess the participants' interest (INT; 7 items; Cronbach's alpha = .92), perceived competence (COM; 5 items; Cronbach's alpha = .77), perceived autonomy (AUT; 5 items; Cronbach's alpha = .72), and perceived relatedness (REL; 8 items; Cronbach's alpha = .77) while performing a given activity. Further, the confidence scale (Bandura, 2006) measured the students' self-efficacy (MCS; 4 items; Cronbach's alpha = .87).

Procedure

Before a year-long implementation of the *McLarin's Adventures* MMOG, the participants received the pretest of the complex problem scenario, which required them to construct their solutions in the form of an annotated causal representation. Then they watched the opening news video announcing the competition by McLarin International to select viable applicants on a space exploration mission. Our pretest data collection (i.e., demographic data and motivation inventory) was introduced at this point as if it was part of the competition in the game to select the applications. A week after the year-long implementation of the *McLarin's Adventures* MMOG, the participants constructed their solutions to the posttest of the complex problem scenario in form of an annotated causal representation and completed the scales of the motivation inventory.

Analysis

The motivation variables of interest in this study reflected the change that occurred between the pretest and the posttest of each variable. In other words, we were interested in the predictive relationship between pre-post change in interest, autonomy, competence, perceived relatedness, and learner engagement. The pre-post motivation variables were the difference scores (Posttest - Pretest), with an increase indicating a greater amount of the motivation variable at the posttest and a negative score indicating a decrease of the motivation variable.

Embedded assessment within an immersive learning environment is regarded as a viable method for making inferences on learner's behaviors (Chung & Baker, 2003). For instance, student engagement during gameplay is assessed by the time spent in the game or the number of tasks completed during gameplay (Reese, Seward, Tabachnick, Hitt, Harrison, & Mcfarland, 2012). Accordingly, the participant's *engagement* (ENG) during gameplay was assessed through log-file data operationalized by (a) the number of tasks completed and (b) the time spent on the game.

In order to analyze the annotated causal representations, the HIMATT (Pirnay-Dummer, Ifenthaler, & Spector, 2010) analysis function was applied. The automated analysis function produces measures, which range from surface-oriented structural comparisons to integrated semantic similarity measures. Those measures include four *structural* (surface, graphical, structural, and gamma matching, also referred as SFM, GRM, STM, and GAM) and three *semantic* (concept, propositional, and balanced semantic matching, also referred as CCM, PPM, & BSM) indicators.

Each of the participants' problem representation (annotated causal representation) was compared automatically against a reference solution. The reference solution included the annotated causal representation, which was used to guide the design of the scenarios in *McLarin's Adventures* MMOG, co-developed by a team of expert teachers of various subject matters. HIMATT uses specific automated comparison algorithms to calculate similarities between a given pair of frequencies or sets of properties. The similarity index *s* for each of the seven measures results in a measure of $0 \leq s \leq 1$, where $s = 0$ is complete exclusion and $s = 1$ is complete similarity.

Reliability scores for the HIMATT measures range from $r = .79$ to $r = .94$ (Pirnay-Dummer et al., 2010). Convergent validity scores lies between $r = .71$ and $r = .91$ for semantic comparison measures and between $r = .48$ and $r = .79$ for structural comparison measures (Pirnay-Dummer et al., 2010).

Based on the HIMATT measures, the dependent variable *problem representation* was identified as a combination of semantic and structural properties: PREP = (CCM+PPM) + (SFM*GRM*STM). The variable is reported for the pre-test ($PREP_{pre}$) and post-test ($PREP_{post}$) results. Based on previous research using the HIMATT measures, the aggregation of structural and semantic measures best reflects individual's problem representation as it includes strong weights of semantic complexity; however, does not neglect the overall structural components (Eseryel, Ifenthaler, & Ge, 2013).

Results

Initial data checks showed that the distributions of ratings and scores satisfied the assumptions underlying the analysis procedures. All effects were assessed at the .05 level. As effect size measures, we used Cohen's *d*.

Engagement

Table 1 shows the zero-order correlations among the variables with regard to the first set of hypotheses. Participants' *engagement* in the MMOG was negatively related to their change in *interest* during the game, as was their change in *competence* during the game. However, participants' *engagement* in the MMOG was positively related to their change in *self-efficacy* while playing the game. Additionally, their change in *interest* was positively related to their change in *autonomy*. Finally, participants' change in *autonomy* was related to their change in perceived *relatedness*.

Table 1. Descriptives and zero-order correlations for engagement and change of motivation variables during gameplay

Variable	1	2	3	4	5	6
1.Engagement (ENG)	-					
2. Interest (INT)	-.303**	-				
3.Competence (COM)	-.257*	.171	-			
4. Autonomy (AUT)	.030	.225*	.019	-		
5. Relatedness (REL)	.043	-.021	.130	.537***	-	
6-Self-efficacy (MCS)	.225*	.109	.038	-.089	-.140	-
M	68.39	-.87	-.89	-.23	-.13	1.78
SD	29.21	1.50	1.88	.99	1.08	19.99

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

A hierarchical regression analysis was used to determine whether the change in motivation constructs during gameplay (interest, competence, autonomy, relatedness, self-efficacy) were significant predictors of *engagement* (ENG) in the MMOG (dependent variable). *Interest* (INT) entered into the equation of step one explained a statistically significant amount of variance in *engagement*, $R^2 = .092$, $F(1, 67) = 6.76$, $p = .011$. After step two, with competence (COM), autonomy (AUT), relatedness (REL), and self-efficacy (MCS) also included in the equation, R^2

= .222, $F(5, 63) = 3.61$, $p = .006$. Thus, the addition of these variables resulted in a 13% increment in the variance accounted for. Specifically, participants' change in *interest* (INT) negatively predicted *engagement* (ENG), indicating that despite the loss of *interest* (INT) during gameplay, the participant's *engagement* (ENG) increased (see Table 2). Accordingly, Hypothesis 1a is rejected. Additionally, participants' change in *competence* (COM) negatively predicted *engagement* (ENG), indicating that despite the loss of *competence* (COM) during the gameplay, the participant's *engagement* (ENG) increased. Accordingly, Hypothesis 1b is rejected. However, the participant's change in *self-efficacy* (MCS) positively predicted *engagement* (ENG), indicating that the higher the change in *self-efficacy* (MCS) during the gameplay, the higher the participant's *engagement* (ENG). Accordingly, Hypotheses 1e is accepted. As shown in Table 3, no correlation was found for *autonomy* (AUT) and *relatedness* (REL). Thus, Hypotheses 1c and 1d are rejected.

Table 2. Regression analysis for variables predicting engagement

Engagement	*B*	*SE B*	*β*
Step 1			
Interest (INT)	-5.92	2.28	-.303*
Step 2			
Interest (INT)	-6.23	2.32	-.319**
Competence (COM)	-3.43	1.78	-.221*
Autonomy (AUT)	3.07	4.05	.105
Relatedness (REL)	1.33	3.68	.049
Self-efficacy (MCS)	.42	.17	.284*

Note. * $p < .05$, ** $p < .01$

To sum up, the results indicate that participant's self-efficacy (MCS) was a significant predictor for their engagement during gameplay (ENG). In contrast, interest (INT) and competence (COM) negatively predicted the participant's engagement during gameplay (ENG).

Problem representation

In the pretest the participants scored an average problem representation score of $M = .926$ ($SD = .329$) and in the posttest $M = 1.071$ ($SD = .414$). The increase in the quality of problem representation was significant, $t(87) = 3.259$, $p = .002$, $d = 0.347$.

Table 3 shows the zero-order correlations among the variables with regard to the second hypothesis. The participant's quality of prior problem representation (before gameplay; $PREP_{pre}$) was positively related to their quality of problem representation ($PREP_{post}$) after playing the MMOG. Also, their engagement (ENG) during gameplay was positively related to the quality of problem representation ($PREP_{post}$) after playing the MMOG.

Table 3. Descriptives and zero-order correlations for engagement and problem representation variables

Variable	1	2	3
1. Problem representation ($PREP_{post}$)	-		
2. Prior problem representation ($PREP_{pre}$)	.387***	-	
3. Engagement (ENG)	.237*	.051	-
M	.926	1.071	62.347
SD	.33	.41	30.18

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

Next, a hierarchical regression analysis was performed to determine whether the *engagement* and *prior problem representation* ($PREP_{pre}$) are significant predictors of the *problem representation* ($PREP_{post}$) after playing the MMOG (dependent variable). *Problem representation* ($PREP_{pre}$) entered into the equation of step one explained a statistically significant amount of variance in *problem representation* ($PREP_{post}$), $R^2 = .150$, $F(1, 86) = 15.17$, $p < .001$. After step two, with *engagement* (ENG) also included in the equation, $R^2 = .197$, $F(2, 85) = 10.44$, $p < .001$. Specifically, participant's *prior problem representation* ($PREP_{pre}$) and *engagement* (ENG) positively predicted *problem representation* ($PREP_{post}$), indicating that the higher the change in *prior problem representation* ($PREP_{pre}$)

as well as *engagement* (ENG), the higher the participant's *problem representation* ($PREP_{post}$) after playing the MMOG (see Table 4). Accordingly, Hypothesis 2 is accepted.

Table 4. Regression analysis for variables predicting post problem representation (N = 88)

Problem representation (post)	*B*	*SE B*	*β*
Step 1			
Prior problem representation ($PREP_{pre}$)	.488	.125	.387***
Step 2			
Prior problem representation ($PREP_{pre}$)	.474	.123	.376***
Engagement (ENG)	.003	.001	.218*

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

To sum up, the results indicate that both the prior problem representation ($PREP_{pre}$) and the engagement during gameplay (ENG) predicted the problem representation ($PREP_{post}$).

Discussion

The importance of cognitive structure (i.e., problem representation) for complex problem solving is undisputed (Ifenthaler & Seel, 2011, 2013; Jonassen et al., 1993; Shavelson, 1974). However, we argue that cognitive structure explains only part of the problem-solving performance during game-based learning. Another important prerequisite for successful problem solving is the problem solver's motivation (Mayer, 1998). In the context of game-based learning, motivation literature particularly emphasizes the influence of self-efficacy and self-determination on the quality and outcome of problem solving (Ryan & Deci, 2000; Zimmerman & Campillo, 2003). Therefore, this study was conducted to better understand the influence of motivation and engagement on the learner's problem representation in the context of game-based learning. Our research model hypothesized that students' problem representation can be explained by cognitive structure (i.e., prior problem representation) and various aspects of motivation.

Regarding our first hypothesis, we assumed that interest, competence, autonomy, relatedness, and self-efficacy have a positive effect on participant's engagement. However, interest and competence negatively predicted engagement, indicating that the higher the loss of interest and competence, the higher the engagement (see Table 2). An in-depth analysis of our data and post-hoc interviews showed that students were initially highly interested in playing the MMOG in the classroom setting. However, the game did not fulfill their expectations (e.g., compared to commercial MMOGs), which caused a decrease of interest in solving the task while playing the game. Despite the loss of interest and competence, the participants kept playing the game. This was mainly because the gameplay was the only classroom activity during the class session. On the other hand, we found a significant positive influence of student's self-efficacy for the tasks on their engagement (see Table 2). Accordingly, students easily overcome the obstacles and tasks in the MMOG, which increased their self-efficacy during gameplay. Accordingly, the results indicated that the increase of self-efficacy led to the increased student engagement putting forth more effort in solving the problem scenarios within the MMOG and being more persistent in pursuing those tasks (Bandura, 1997; Zimmerman & Campillo, 2003). The students' perceived autonomy and experience relatedness did not influence their engagement.

Regarding our second hypotheses, results indicated that student's engagement and their prior problem representation had a significant positive influence on their problem representation. Clearly, prior problem representation and engagement were strong predictors of student's problem representation after playing the MMOG, that is, the higher their engagement and prior problem representation, the higher their final learning outcome. Therefore, it is concluded that one of the critical issues in designing educational games is to sustain student motivation over time during gameplay. Since students are curious beings and like to seek novelty and explore problems, one way to address the issue of sustainability is to provide students with new and challenging game scenarios as they move along in their gameplay tasks to keep them motivated and focused. On the other hand, if students perceive their problem-solving competence increase in MMOG over time, they would be even more motivated and willing to invest more time and effort in the problem-solving tasks (Mayer, 1998; Ryan & Deci, 2000).

Implications

The findings of this study showed that, due to the challenges associated with complex problem solving, student motivation and engagement have crucial impact on students' development of complex problem-solving competencies in game-based learning. Furthermore, contrary to the current discourse and beliefs of its proponents, the findings of this study suggested that while games may be complex problems to be solved by students, playing educational games do not necessarily lead to improved problem representations. Hence, there is a critical need for empirically-validated instructional design frameworks to leverage the affordances of game-based learning to design effective situated learning environments that can engage learners and support their development of complex problem-solving competencies. The results of this study also implied that such a design framework should clearly articulate on the design principles and approaches to scaffold learners' motivation and cognitive structures to sustain high-level engagement during gameplay.

Based on the findings of this study and our formal observations during implementation, we argue that there are three modes of interactions that should be carefully designed in educational games to sustain motivation and engagement (Figure 2): (1) *interface interactivity*, which refers to the direct interaction between players and game systems; (2) *narrative interactivity*, which refers to the interaction between the players and the storyline; and (3) *social interactivity*, which refers to the communication and collaboration between human players (see Eseryel, Guo, & Law, 2012 for more details).

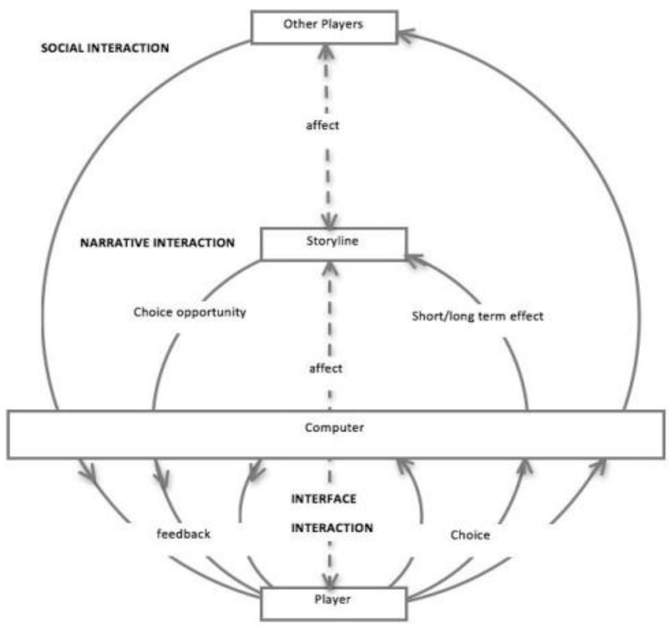

Figure 2. Three-levels of interactivity design for educational games

As shown in Figure 2, all of these interactivity levels should be designed to complement each other in scaffolding learners' development of complex problem-solving competencies. For instance, realistic immersive interface interactivity is crucial in enabling effective narrative interactivity and in conveying necessary *messages* to the players. In the *McLarin's Adventures* MMOG, a red road was built to guide players' wayfinding; however, we noted that such an approach may negatively affect players' sense of autonomy.

Findings of this study also suggested that, in order to sustain student motivation and engagement, it is necessary that the individual tasks are not fragmented pieces of overall complex problem scenario in the game narrative. For instance, in the *McLarin's Adventures* MMOG, one of the problem scenario calls for building a settlement area. This is a complex problem. However, in the game, this problem was broken down into discrete tasks, such as calculating the area of the island. We often observed that students, who started playing the game with high enthusiasm, started complaining after a short while, "this is not a game!" Therefore, we argue that traditional instructional design models, which require fragmentation of learning objectives (e.g., remembering a fact, applying a procedure, understanding a concept), are not appropriate for designing narrative interactivity due to a lack of challenges to intrinsically motivate students.

Findings of this study also suggested that social interactivity during gameplay, such as competition and collaboration with others, plays an important role contributing to learners' motivation, engagement, and development of complex problem-solving competencies. For instance, the backstory of the *McLarin's Adventures* MMOG required players to assume different scientist roles to complete the tasks while playing the game in teams of four. Initially, this led to increased engagement. However, because the tasks did not truly require collaboration among team members with different expertise or roles, the students soon discovered that the tasks in the game had to be completed by each player individually to get game points. When we examined the chat and voice logs of the game, we found that student collaboration noticeably declined as the game progressed; instead a very large portion of the chat content was irrelevant chatter. Hence, we concluded that lack of social interactivity embedded in the game narrative might have negatively affected students' motivation, engagement, and learning.

Limitations and future work

As with all experimental research, there are limitations to this study, which need to be addressed. First, while our sample size was large enough to achieve statistically significant results, the explained variance for our regression models was rather moderate. This indicates that besides the tested variables other variables may have influenced the outcomes, which were not tested in this study. In contrast to laboratory experiments, design-based research limits the validity due to influences that cannot be controlled outside the study's intervention.

Second, the issues in game design may have contributed to moderate variance. Thus, our future plans include further investigations when the design of interface, narrative, and social interactivity dimensions are improved per discussion in the previous section.

Third, the implementation of the MMOG needs to be addressed. Our implementation model followed the minimal-external-guidance model where teachers acted solely as facilitators. In contrast, games may also be implemented with a strong emphasis on guidance. Accordingly, future studies are needed to address the effectiveness of different instructional models for implementing game-based learning (Kirschner, Sweller, & Clark, 2006).

Last, assessment of game-based learning is challenging and it is being questioned. Only very few empirical research studies exist that used valid and reliable methods for assessing complex problem solving in game-based learning (Eseryel, Ge, Ifenthaler, & Law, 2011). There is a need for established assessments methods that can be embedded in educational games to determine engagement, progress of learning, and development of complex problem-solving competencies (Ifenthaler, Eseryel, & Ge, 2012a). Accordingly, future generation of educational games should include embedded assessments and provide instant analysis of a wide variety of 21st century skill acquisition and offer personalized feedback to learners (see Eseryel, Ge et al., 2011; Eseryel, Ifenthaler, & Ge, 2011; Ifenthaler, Eseryel, & Ge, 2012b).

Conclusion

This study shows that motivation and engagement in a game-based learning environment have an impact on learners' problem-solving outcomes. Thus, it is crucial to design game-based learning environment to scaffold students' motivation and engagement. Not all the games are necessarily designed as complex to engage students in problem-solving tasks; therefore, the assumptions that all games are engaging and that playing games will increase learners' problem-solving skills are challenged. This study reveals that (1) there are complex interplays between the student engagement, motivation, and problem-solving competencies; (2) the game can enhance or limit learners' choices and relatedness, which can influence learner engagement; and (3) the design features of the game can affect learners' self-efficacy and perceived competence. Therefore, in order to foster students' complex problem-solving competence, educational games should be designed in a way that provides complexity for students to engage in problem-solving tasks, with sufficient autonomy for students to make choices and attainable challenges to help them move closer to their intended goals.

This study was among the first that explored the complex relationships between motivation, cognition, and instruction in the context of digital game-based learning. There are many further questions to be explored in the future; for example, how to design optimal educational games that have the appeal of a commercial game; how to directly capture the data of students' activities and emotions during gameplay; and how to measure and assess learners' mental effort, cognitive load, decision-making, and other self-regulation processes. Scientific inquiries along these lines will help us to advance research on complex problem solving in the digital age.

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