Applying Interest Loop to Develop Game-based Model for Chinese Character Learning

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Abstract: Interest is a critical element for student learning and should be cultivated. To this end, different interest development models have been investigated. This study focuses on interest loop, which comprises three components, including triggering, immersing, and extending interest. Based on the interest loop, this study proposes a game-based model for Chinese character learning. In addition, a learning system, named CharacterMonster, is also implemented to realize this conceptual model for examining its feasibility. The detailed functions of the system are described in this paper.

Keywords: Game-based learning, Interest loop, Chinese character learning

1. Significance of interest

Interest, which involves how students pay their attention and make their efforts, has been regarded as a significant and foundational element of learning (Wong, et. al., 2015). Previous studies have demonstrated that interest would influence student learning in terms of various aspects, such as performance (Schraw, Flowerday, & Lehman, 2001), self-efficacy (Hidi, Berndorff, & Ainley, 2002), and self-regulation (Sansone, Thoman, & Smith, 2000). In addition, some studies further assert that interest could be cultivated through some models, such as four-phase model (Hidi & Renninger, 2006) and interest loop model (Wong, et. al., 2015).

For four-phase model, interest is viewed as malleable forms of interests, including triggered situational interest, maintained situational interest, emerging individual interest, and well-developed individual interest (Hidi & Renninger, 2006). The former two (i.e., triggered and maintained situational interest) could be triggered by environmental stimuli, whereas the latter two (i.e., emerging and well-developed interest) could emerge after triggering and maintaining situational interest.

For interest loop model, interest comprises three components, including triggering interest, immersing interest, and extending interest. The three components link to each other and form as a loop. In addition, the three components are respectively characterized by three general design strategies: curiosity, flow, and meaningfulness. For triggering interest, curiosity could invoke students to seek out personal interests (Deci, 1975) through information gap (Loewenstein, 1994). When interest is triggered, students might involve themselves fully in a learning activity, leading to flow experience (Csikszentmihályi, 1991). Besides, knowledge and interest could reinforce each other (Silvia, 2006) to enrich prior knowledge and meaningful learning, which in turn extends interest.

2. Game-based model and system for Chinese characters

Figure 1 illustrates the conceptual model of the game-based model for Chinese character learning. The game-based model is underpinned by the interest loop. Specifically, the game-based model consists of three game components, and each game component is developed based on the three components of interest loop, respectively (i.e., triggering, immersing, and extending interest). According to the conceptual model, a game-based system for Chinese character learning is implemented. The learning
system, named CharacterMonster, is characterized as a type of nurturing games, whose goal is to gather a number of fantasy monsters and nurture them. The details of the three game components of CharacterMonster system are described as follows:

### Figure 1. Interest loop and game-based model

**Embodying characters as cartoon monsters**

**Feeding monsters by handwriting characters**

**Collecting monsters for the album of character radicals**

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**Triggering component:** to arouse curiosity as the design strategy for triggering interest, radical components of Chinese characters are represented as cartoon monsters. For instance, the radical component of “木” is represented as a “deer” monster that eats Chinese characters with the “木” radical, as illustrated in Figure 2. Similarly, the radical component of “日” is portrayed as a “phoenix” monster that eats Chinese characters with the “日” radical. In other words, these radical components are not only shown by symbols, but also embodied as cartoon figures. Such representations might arouse students’ curiosity about their appearances (e.g., what kind of monsters they are), history (e.g., how they are evolved), and food (e.g., which Chinese characters they want to eat). Such design might form as “knowledge gap” (Loewenstein, 1994) to inspire students to learn Chinese characters.

![Figure 2. Triggering component of CharacterMonster system](image)

**Immersing component:** to engaging students in mastering Chinese character writing, the strategy of “learning by feeding” (Chen, 2012) is used. Students play the role of keeper to nurture these character monsters by feeding correct Chinese characters. Specifically, the students have to write Chinese character correctly, and then feed monsters. For instance, to satisfy the “deer” character monster, the students are required to learn how to write Chinese characters with the “木” radical component, and use these Chinese characters (e.g., 林, 森, 株, 枯, 校, 樹, 橘) to feed the monster, as
shown in Figure 3. Similarly, the students need to learn how to write Chinese characters with the “日” radical component, and use them (e.g., 早, 是, 明, 昭, 晒, 昭) as food to nurture the monster. By doing so, the students could understand the relationship between Chinese characters and their radical component in a more interesting way, which might, in turn, offer student more opportunities to create optimal experience in learning.

![Figure 3. Immersing component of CharacterMonster system](image)

Extending component: to extend student’s interest for Chinese character, an album system is designed to collect all of these character monsters (see Figure 4). While students collect these character monsters, it implies that students have more opportunities to relate and integrate the old knowledge with new knowledge through the album. In addition, collecting is also meaningful for students to enrich what they have already learned, where students’ ownership and achievement might extend their interest both in breadth and in depth. In other words, the album system maintains a structure not only for re-organizing old knowledge, but for exploring and discovering new knowledge.

![Figure 4. Extending component of CharacterMonster system](image)
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References

Cultivating Students’ Writing Habit in a Game-based Learning Environment

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Abstract: This study focused on delineating and utilizing “habit loop” framework: cueing environment, routine, and satisfaction. This study further integrated the habit loop framework into portfolio management game for helping elementary school students to write and rewrite to cultivate good writing habit. According to the habit loop framework, we also proposed two design principles: portfolio visualization and management. The former supports cueing environment; the latter increases satisfaction. Students performed their routines (i.e., writing and rewriting) in a portfolio management game. Briefly, this study creates an environment more conducive to students’ writing to cultivate their consistent habit.

Keywords: portfolio management game, writing habit, habit loop

1. Habit and Habit Loop

Practitioner, educators, and parents have long acknowledged the importance of cultivating students’ good habit for writing (Duhigg, 2012) because writing involves a persistent and stable change in what students know or does (Zimmerman, & Risemberg, 1997). Forming useful and productive writing habits is important for students. Specifically, habit formation is often related to interest and persistence. Briefly, habit is a routine of behavior that is regularly repeated and tends to occur unconsciously (Durhigg, 2012). “Habits are the result of automatic cognitive processes, developed by extensive repetition, so well-learned that they do not require conscious effort” (Ronis, Yates, & Kirsch, 1989, p. 219).

While considerable attention has been paid in the past to research issues of Health Psychology (e.g., drinking a lot of water or doing exercise regularly), the literature on issues of Educational Psychology has emerged only very slowly and in a more separate way. A previous study (Chen, Chan, Liao, Cheng, So, & Gu, 2015) proposed a framework of “James’ Habit Loop” to promote habit formation. In particular, Chen et al. (2015) adapted from the framework of Durhigg (2012) (i.e. a cue, a routine, and a reward) and, proposed a habit formation framework in the context of education and learning which consisted of three components: cueing environment (e.g. arrangement of place, time, people, or incidents), routine (e.g. repetitive pattern of activities), and satisfaction, forming the habit loop, see figure 1. In other words, habits are automatic behavioral which responses to environmental cues, develops through repetition of behavior in consistent contexts, and reinforces a students’ satisfaction. In short, to create a habit, students need to repeat the behavior in the same situation.

Moreover, it is known that the game-based learning approach has great potential for facilitating the engagement of students in learning activities. For example, Proske, Roscoe, & McNamara (2014) explored the motivational aspect, like in game-based practice for writing. Many researchers also believe that sustaining motivation is critical for transforming learning from the use of digital games to educational goals (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). Essentially this framework is a phenomenal hypothesis and lacks empirical investigation; hence this study integrated this idea of habit loop into portfolio management game, entitled Creation-Island (Liao, Chang, & Chan, 2016) for helping elementary school students to write and rewrite to cultivate
In other words, this study created an environment which is more conducive to students’ writing to cultivate their consistent habit. Besides, daily writing habit not only shows a way to think out loud but also deepens a conversation with oneself. If students could get in the habit of writing every day, writing habit will help students to organize one's thoughts and get one's ideas. We hope it could help students form a new good habit and break old “not-so-good” habit. In short, this study adopted that the habit loop with game-based learning approach to provide a mechanism for establishing new behaviors and writing habit formation.

Figure 1. James’ Habit Loop

2. **Portfolio Management Game**

Creation-Island (Liao, Chang, & Chan, 2016) provides an engaging island-construction environment which students can build and maintain an island with residential, commercial, and industrial buildings (i.e., reading for creating), and invest myself money from other students’ island in order to attract tourists’ attention and interest (i.e. talking about revising). In particular, the Creation-Island incorporates many elements into an island, using a simplified interface designed to be intuitive for young students. Follow habit loop framework, and this study proposed two design principles: **portfolio visualization** and **management**. The former supported cueing environment; the latter increased satisfaction; students perform their routine (e.g., writing and rewriting) in a portfolio management game.

2.1. **Portfolio Visualization: Creation-Island as Open Student Model**

This first design principle is related to the information visualization of students’ portfolios which helping them to understand their efforts, progress, and achievements (Paulson, Paulson, & Meyer, 1991). From a broader perspective, the visualization of students’ portfolios is related to the concept of open learner models are learner models that are accessible to the user (Bull, & Kay, 2007). Recently, open learner model also designed in sophisticated form, such as animal companions to motivate children to learn (c. f. Liao, Chen, Cheng, Chen, & Chan, 2011). These studies found that the strategy providing different perspectives towards open learner models have positive impacts on students. Because of opening students’ portfolios what students have learned to the students themselves and allowing them to observe, edit, or negotiate with the educational system as well as interact with learning peers (Bull & Kay, 2007).
Thus, this study proposes a design principle to visualizing the learning products and habits for students in educational settings, and to concretize the learning portfolios so that students can become more aware of their learning status and further cultivate their good habit of writing. For example, login bonus is rewards given for logging and writing into the Creation-island daily, see Figure 2. These rewards include Educoins and Experience point. There are two different login bonuses, a consecutive bonus and total days logged bonus. The following login bonus rotates on a 5-day cycle. Once students finish the cycle, the game does not reset the number of days, but the rewards do reset. If students miss one or more days and break the consecutive login streak, the next time you log in will begin at day one again.

2.2. Portfolio Management: Writing Daily Record as Self-monitoring

The second design principle is related the portfolio management of students’ writing activities which help them to record daily writing. Kay (1997) advocated the usage of learning profiles to promote self-reflection and self-monitoring, and stated: “it should make it available to the learner for improving their learning through better self-knowledge (Kay, 1997, p. 18)”. In Creation-island, the buildings changing provides the student with a “visible” learning status. In particular, the statuses of island map change according to the students’ learning progress and performance. In this way, the students’ awareness of self-reflection might be enhanced.

Moreover, existing research agrees upon the critical role of self-monitoring during writing (Graham, Harris, & Mason, 2005) especially for learning to write. In other words, based on previous literature on the key role of self-monitoring in self-regulated learning, students were provided with opportunities to self-monitor their writing through self-evaluations on both their writing.

Hence, this study proposes that daily writing record may promote students’ monitoring on their writing, see Figure. 3. In particular, Creation-island provided a personal tracking tool (i.e., writing habit records) as the weekly report. It keeps track of students’ writing trends and gives student daily stats on their writing as well as badges for their accomplishments that keep things fun. Keeping track of trends could a very powerful tactic for developing any new habit. Briefly, this study designed a calendar in Creation-Island and marked a record for every day that students worked on their routine (i.e., writing). Eventually, students’ trend became so long that he kept going just because a student didn’t want to break it.
Remarks

This study focused on delineating and utilizing “habit loop”: cueing environment, routine, and satisfaction. Based on above idea, this study also proposed two design principles: portfolio visualization and management to cultivate students’ good habit for writing in a portfolio management game. In other words, Creation-island is a portfolio management game where supports students to do their daily writing. In Creation-Island, students could build their island or invest others’ islands to practice different theme-basic articles at the same time. To make writing a regular practice and reach to game goal, students have to develop regular habits in their learning process. To exert a long-term impact on student writing learning, a natural way is to cultivate writing with interest as a habit, desirably a lifelong habit.

The upcoming work is to experiment in a 4th-grade classroom as a pilot. In the experiment, we are going to involve our design in the writing courses. The designed activity will be a task of their Chinese class. In particular, teachers could use Creation-Island as a part of their classroom instruction for students to practice and master specific concepts. Students could also use Creation-Island on their own time and at their own pace to prepare for writing that is more difficult for them to understand. Hence, we will have an opportunity practically to examine the habit loop frameworks in a primary school to understand students’ behaviors and competence for writing habit. Next, we will also explore this framework to understand whether cultivating students’ good habit for writing. We hope that future research will provide more detailed results.

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References


Creation Loop Example of IDC Theory: CoCoing.info

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Abstract: Advocated by a group of Asia researchers, a design theory named IDC (Interest-Driven Creator) is proposed to support system designers to design learning system. The IDC theory as a learning-activity design theory has three major anchored concepts that are Interest Loop, Creation Loop, and James’ Habit Loop. Furthermore, each of the anchored concepts has three well-defined components. For instance, the Creation Loop of the IDC theory is consisted of acquiring, combining, and staging components. From a learning system design perspective, the IDC theory provides a useful reference framework to guide the system designers on how to design a learning system. In this article, guided by the Creation Loop anchored concept of the IDC theory and the Creation Loop components, a social networking platform named CoCoing.info is implemented and illustrated. Learners on the platform can acquire their knowledge collaboratively, combine their knowledge in a shared workspace, and stage to present their work in the classroom. The developing experiences of the CoCoing.info indicate that a well-designed developing guideline such as the IDC theory provides system designers an effective and accurate developing process.

Keywords: IDC Theory, creation loop, CoCoing.info, social networking platform

1. Introduction

With technology evolution, learners utilizing information and communication technology (ICT) like mobile phone, tablet, and laptop computer can easily practice their learning activities anytime and anywhere (Wong, Milrad, & Specht, 2015). This movement has undoubtedly affected how people learn (Sawyer, 2005). However, adopting ICT to enhance learning requires a deliberate design (Chan et al., 2006) since designing ICT in learning is an interdisciplinary study covers various domains, such as social interaction, learning behavior analysis, educational goal, learning activity design and, no doubt, ICT. From an ICT enhanced learning designer perspective, too many design variables make ICT enhanced learning system design very challenging and difficult. Therefore, a well-elaborated reference framework might provide the designers a clear direction on how to design a learning system effectively and accurately.

To let the designers a clear design guideline, a group of Asian researchers has been developing an Interest-Driven Creator (IDC) theory which is a design theory based on three anchored concepts. The three anchored concepts are Interest Concept, Creation Concept, and Habit Concept. Each of these concepts is represented by a loop that comprises three components. For example, Interest Loop is consisted of Triggering, Immersing, and Extending components; Creation Loop is consisted of Acquiring, Combining, and Staging components; and James’ Habit Loop is consisted of Cuing Environment, Routine, and Satisfaction. With technological support, the IDC theory developers advocated that the design of learning activities based on the IDC theory will enable students to develop their interest in learning.

When adopting technology in learning, a well-designed framework will improve the design quality (Chan et al., 2006). With technological support, the learning activities design based on the IDC theory will enable students to develop their interest in learning. In this study, by adopting the Creation loop of IDC theory, a social networking learning system named CoCoing.info is illustrated. On the CoCoing.info system, the learners can acquire knowledge, combine knowledge, and stage to present their combined outcomes. The experience of adopting IDC theory on designing the
CoCoing.info platform reveals that following a deliberate learning theory enables the designer paying much attention to the learning system design systematically and accurately.

2. **CoCoing.info: An Illustrating Example of the Creation Loop**

2.1. **CoCoing.info Use Case**

As mentioned above, the IDC theory designers argued that learning can be regarded as a process of creation and vice versa. Based on the Creation loop anchored concept, the Creation loop is further decomposed into three components which are acquiring, combining, and staging. Meanwhile, each of the three creation components can be a standalone learning activity. From the design point of view, the decomposed components design as a reference framework is helpful to guide the system designers to design their learning system. Based on the design philosophy, a social networking platform named CoCoing.info is designed (Shih & Chang, 2016). Figure 1 draws an outline of how the CoCoing.info platform fits into the Creation loop concept. As displayed in Figure 1, based on the three creation loop components, three screenshots are shown to illustrate the three components, correspondingly.

![Figure 1. The Creation Loop and the CoCoing.info Platform.](image)

The CoCoing.info is a social networking platform where learners could construct and share their personal concepts to themselves, to their friends and groups, and to the public. Figure 2 illustrates the CoCoing.info platform design, which provides functions that enable learners to acquire knowledge, combine knowledge and stage to share their knowledge.
2.2. CoCoing.info on Acquiring Stage

According to the IDC design theory, at Acquiring stage, the designers concern taking in inputting knowledge from the outside world to build one’s background knowledge. When speaking of creation, there are two possibilities. They are the individual creation and group creation. Those design principles were adopted in the CoCoing.info design process.

On CoCoing.info platform, to facilitate learners to build their background knowledge, each learner has a personal space to build their concept map. Adopting concept map on CoCoing.info is because concept map is an effective tool and has been widely applied in various learning fields (Novak, 1995; Novak, 1998; Cañas & Novak, 2008; Chiou, 2008), and concept map can be applied to assess learner’s understanding (McClure, Sonak, & Suen, 1999). On the CoCoing.info platform, for a specific topic, learners are provided with a set of tools to acquire their knowledge by drawing out their concept map. A learner on the platform can not only acquire knowledge individually but also from a group to explore knowledge collaboratively. All the students invited can be involved in the group concept building activity.

Figure 3 illustrates an instance of a person’s concept map. The learner draws out the concept after completing a book reading. The top of the figure is the book’s title. Below the title, the student can explicit their idea by adding new concept nodes. Each user can represent and explicate their personal concepts through the user interface displayed in Figure 3. On the CoCoing.info platform, the user can create an idea and then add a node, delete a node, color a node or add text on the selected node based on the created idea. Through the interface, the user can easily draw out their concept.
Figure 3. The Acquiring Stage of a CoCoing.info activity.

2.3. CoCoing.info on Combining Stage

The IDC theory indicates that the learners at Combining stage refer to generate new ideas or things by combining existing ideas which have not been combined before. Based on the IDC theory guideline, the students on the CoCoing.info platform are formed as a group to combine their knowledge. Before entering this stage, all the students have built enough background knowledge at the Acquiring Stage.

Figure 4 displays an instance in which all the students build their background knowledge to construct an idea collaboratively. At this stage, the teacher just gives the students a topic and a guideline of the topic. The student based on the teacher’s introduction and their background knowledge to discuss their idea, and then to combine a new product with their peers.

At Combining stage, the students learn how to express their ideas effectively. In the process, they can learn from each other, help each other, be recognized by each other, and build their self-confidence.

Figure 4. The Combining Stage of a CoCoing.info activity.

2.4. CoCoing.info on Staging Stage

According to the IDC theory statement, the Staging stage relates to improving the novelty and value of the created product through interactions with a community. Once the students have completed the Acquiring Stage and Combining Stage, they have enough background on the specific topic with combined knowledge. They are, at the Staging Stage, ready to present their knowledge to their peers and to get feedback from their peers.
Figure 5 shows an example of a student who is presenting the combined idea. With the CoCoing.info platform, the student can easily show their idea on the screen and present their work to their peers.

![Figure 5. Staging Stage of a CoCoing.info Activity.](image)

3. **Discussion and Conclusion**

As mentioned above, guided by the IDC theory, in short, creation is the process of acquiring, combining, and staging to refine knowledge. By creating, they progressively expand their relevant communities, sustaining their effort to contribute to them, building their self-esteem, and ultimately attaining self-actualization. Acquiring stage lets students build their background knowledge for further discussion. Combing stage triggers students to exchange and to consolidate idea, and Staging enables students to receive peer feedbacks for improving their creations’ novelty and value.

In this study, based on the IDC theory guideline, the authors report a platform named CoCoing.info. On CoCoing.info, the users can practice the three concepts of the IDC Creation loop that consists of Acquiring, Combining, and Staging Stages. Students on the CoCoing.info platform can acquire knowledge personally in a concept map format, combine their knowledge with their peers, and then stage to present their idea to their peers to collect feedbacks.

Learning activity design is a complicated process. Designers will encounter difficulties if they try to manage too many complex design concepts simultaneously. More specifically, for a system designer, handling too many design concepts especially educational design concepts at the same time will let the user hard to focus on developing the learning system. With the IDC theory, only anchored concepts—interest, creation, and habit—are considered. With these anchored concepts, designers can begin to design at a macro-level, component concepts. The developing experiences of the CoCoing.info indicate that such kind of well-designed developing guideline theory provides system designers an effective and more accurate developing process.

**References**


Minecraft as a Sandbox for STEM Interest Development: Preliminary Results

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Abstract: After a brief review of the science of interest and the game of Minecraft, we present a taxonomy of common Minecraft actions and activities and propose that they represent links to specific STEM disciplines. We then discuss the development of a Minecraft survey intended to identify STEM-related interests, and present the results of a pilot study using the survey in three Minecraft camps held in the summer of 2017. We describe the most and least popular Minecraft activities, and report initial analyses of the surveys, revealing potential connections in the earth, biological, and environmental areas of STEM.

Keywords: interest, educational games, Minecraft, STEM education, informal learning

1. Interest and its impact on learning

1.1. Why interest matters

The presence of interest can have a profound impact on an experience. For example, someone who loves the game of baseball is more likely to enjoy a low-scoring, nine-inning game (even perhaps deeming it a “chess match”), while one who lacks that interest is more likely to leave by the 6th inning. Research has repeatedly demonstrated that interest in a topic (like baseball) has a powerful influence on one’s perceptions, beliefs, memories, attitudes, and willingness to learn more about that topic (Krapp, 1999; McDaniel, Waddill, Finstad, & Bourg, 2000; Renninger, Nieswannd, & Hidi, 2015b; Silvia, 2006). Hidi & Renninger (2016) summarize what research on interest has revealed:

People who are interested in what they are doing are recognizable because they tend to have positive feelings, be invigorated, and choose to reengage with a particular object/activity/idea, or content, repeatedly. Their engagement with the content is distinctive and appears to be self-sustaining; their interest positively affects their attention, goal setting, comprehension, motivation, and learning, and it can influence their ability to achieve and succeed in their careers (p. 1).

Interests do not emerge from thin air, of course, and are influenced by a wide range of contextual and experiential factors. For example, an attendee at a baseball game who is not really interested in the sport might be drawn in by the passion and excitement of the other fans. Children at a science museum may have their interest triggered in zoology after petting a worm or holding an insect. In this paper, we address the more basic question of how choices made while playing a video game may reflect potential interests in Science, Technology, Engineering, and Math (STEM). Specifically, we ask to what extent specific Minecraft activities may reflect interest in STEM disciplines.

1.2. Defining interest

Early empirical research employing measures based primarily on affect tended to describe interest as an emotion (Ainley, 2007; Reeve, Jang, Hardre, & Omura, 2002). More recent formulations present interest as a more complex construct that incorporates cognitive and temporal components. Renninger, et al. (2015b) describe five characteristics on which researchers tend to agree:

1. Interest refers to interaction with particular content (e.g., physics).
2. Interest exists as a relation between the learner and the environment.
3. Interest has both affective and cognitive components, which can vary over time.
4. Learners may or may not be consciously aware that interest has been triggered.
5. Interest has a neurological/physiological basis – it is rewarding and linked to approach behaviors.

At this stage of our work, we adopt the simplistic view that interests can be inferred via likert ratings to judge interest in Minecraft play and STEM fields, but will adopt a longer-term orientation for our upcoming studies.

1.3. Consequences of interest

The many positive consequences of establishing interest and its facilitating effect on learning are well-documented (Hidi & Harackiewicz, 2000; Renninger, Nieswandt, & Hidi, 2015a). When a learner is interested, that interest can actually feed on itself and grow (i.e., it is self-sustaining) (Barron, 2006). As a result, motivation to learn and attitudes about content improve (Potvin & Hasni, 2014), achievement and performance in school improves (Harackiewicz & Hulleman, 2010), and learners are more prone to establish deep conceptual understanding than are those lacking interest in the subject (Andre & Windschitl, 2003).

One of the most important findings is that interest is malleable and can change over time. A four-phase model (Hidi & Renninger, 2006) captures this malleability as two primary forms of interest: situational interest, a product of environmental features, followed by individual interest, a relatively self-motivating and enduring state that is marked by reengagement over time. Two sub-phases of each lead a four-phase model: 1) triggered situational interest can become 2) maintained situational interest, then under ideal conditions 3) emerging individual interest can grow into 4) well-developed interest, an enduring and resilient state. In learning contexts, a trigger is simply some experience (e.g., touching a worm) that establishes engagement and involves contextual features (Renninger & Bachrach, 2015).

Importantly, a well-developed interest has been linked to higher levels of self-efficacy and decreased negative self-perceptions (Lipstein & Renninger, 2006) and is predictive of future academic choices (Harackiewicz, Barron, Tauer, & Elliot, 2002). Conversely, an absence of interest can hinder a learner’s willingness to engage or persist (Nieswandt, 2007; Sansone, Fraughton, Zachary, Butner, & Heiner, 2011). Interest both emerges from experience and is heavily influenced by context. Our ongoing research integrates both of these aspects, and seeks to inform the design and deployment of educational technologies in informal learning contexts. How to foster interest development is a critical question with widespread implications for parents, educators, researchers, and policymakers. Appropriate triggers and continuing opportunities to pursue those interests are needed if interest is to flourish, both independently and with encouragement.

1.4. Research aims

We are engaged in a research project investigating the impact of video game play on STEM interest. Specifically, we are interested in two key research questions: 1) In what ways does use of modern entertainment technologies influence learners’ interest in STEM? And 2) How can game-based learning experiences be deployed to trigger interest in specific areas of STEM? In this paper, we focus on the first question and in the context of Minecraft, a game rich in STEM connections. We are also designing customized versions of Minecraft (i.e., via “mods”) that focus on Astronomy. The work reported in this paper focuses on the first research question, and lays the groundwork for linking interests to game play.
2. Minecraft

2.1. Why Minecraft is relevant for education

*Minecraft* has seen a dramatic rise in its adoption by educators worldwide who use it for educational purposes (Schifter & Cipollone, 2013; Schwartz, 2015). The simplest probable reason for its rise is that interactions in *Minecraft* involve a broad range of educationally relevant content, and how one learns to play the game is entirely compatible with classical and modern theories of learning (Lane & Yi, 2017). For example, in *Minecraft*, players routinely engage in activities that involve:

- Exploring and investigating different biomes and climates that match those on Earth, including deserts, forests, jungles, taigas, and many others.
- Navigating in and around different types of terrain, such as hills, mountains, caverns, caves, oceans, and more.
- Interacting with a wide variety of wildlife and agricultural content, including animals, fish, birds, wheat, grass, fruits, vegetables, and a long list of fictional content.
- Searching for, mining, collecting, and combining many different resources such as different kinds of wood, stone, metal, dirt, and more.
- Building electrical circuits, switches, and complex machines.

Players have even reconstructed world wonders, many of which can be found online (e.g. YouTube, dedicated servers) that are virtual copies of actual structures like the Taj Mahal or fictional places, such as Westeros from the *Game of Thrones*. To achieve such feats of engineering, players often work collaboratively by planning and coordinating their tasks. They assume roles (e.g., as resource collectors, planners, builders, etc.), work iteratively to refine their creations, and of course, share their work with friends, family, and the online community. In this paper, we ask what the choice to engage in such activities implies in terms of young players’ interests.

2.2. The popularity of Minecraft

Since Markus Persson released an early version of Minecraft in 2009 (with the official release coming in 2011 through his Swedish company, Mojang), millions of children across the world have chosen to spend hundreds of thousands of cumulative years playing. With well over 100M players, 241M logins per month, and 2B+ hours played on Xbox alone\(^1\), in 2016 Minecraft ascended to be the second most popular game in history (passing Grand Theft Auto V but still well behind Tetris) (Peckham, 2016). One report that looked at server usage data identifies 15-21 year olds as the largest demographic (43%) and children under 15 as the third largest (20.6%).\(^2\) Another way to think about its reach is that millions of children worldwide have decided to interact deeply and meaningfully with a simulation of the natural world. Given this, we believe that it is probably having some influence on the way they think about the world around them – what it consists of, how it works, how we manipulate and exist in it, the use of resources, etc., and we wish to gain insights into how.

2.3. What is Minecraft?

Simply put, *Minecraft* is played in a world made entirely out of blocks. The various blocks encountered in the game have different compositions and functions, such as many variants of stone, wood, and metal. Even liquids, such as water and lava, are modeled as block units, although they adhere to natural laws such as gravity and flow accordingly. Prior to starting a single-player game, the terrain (i.e., a virtual world) must be generated. These digital worlds are huge. The exact cubic

\(^1\) [http://www.wired.com/2015/05/data-effect-minecraft/](http://www.wired.com/2015/05/data-effect-minecraft/)

\(^2\) [http://minecraft-seeds.net/blog/minecraft-player-demographics/](http://minecraft-seeds.net/blog/minecraft-player-demographics/)
volume area of a Minecraft world is two hundred sixty-two quadrillion by one hundred and forty-four trillion blocks (West & Bleiberg, 2013). The terrain generation algorithm produces remarkable (block-style) landscapes and includes features found in the natural world, such as varying biomes (e.g., desert, forest), caves, mountains, oceans, rivers, and lakes (Figure 1 shows two typical screenshots).

Figure 1. Typical Minecraft interactions. The left screenshot shows a player-constructed shelter on the hillside above a creek with animals. The right screenshot shows a crafting screen where the player can create new items (like an anvil) from more basic items (like iron ingots).

In stark contrast to a majority of commercial games, *Minecraft* does not include an active narrative or set game play objectives. Nor is there a direct way to “win” or even obvious ways to “level up,” although some elements of experience points are used and patterns have emerged for imposing goals (e.g., killing the Ender Dragon). The two most commonly used game modes are: *Survival*, where the player must actively seek resources, craft tools, build safe houses, and fend off monsters each night to survive as long as possible; and *Creative*, in which monsters are non-aggressive and players are invincible, can fly, and are given an unlimited supply of resources. Survival mode is more action packed and stressful, while Creative mode is typically for large-scale projects and experimentation.

### 3. A Taxonomy of Minecraft Activities

In order to more formally approach analysis of *Minecraft*, we first created a *Minecraft* action/activity taxonomy. To begin, we reviewed documentation, research literature, discussion boards, *Minecraft* wikis, and talked with expert players to create a master list of actions. The first three authors independently organized the actions into groups, then came together to form an overarching structure. Common but significant in-game actions were selected, and six categories with subcategories emerged (see Figure 2).

We then tagged each action using the 2010 Classification of Instructional Programs (CIP) Codes from the US Dept of Education and National Science Foundation in the order of highest relevance. CIP codes provide structure for STEM fields, skills, and professions. The purpose of the CIP is to support the tracking and reporting of fields of study and program completions activity. When combined with our *Minecraft* action taxonomy, the resulting tags become our claims of relevance to those STEM fields. The links trace each action taken to specific STEM contents. For example,

---

3 https://nces.ed.gov/ipeds/cipcode/
building a functioning clock from scratch in Minecraft requires an understanding of circuitry, the ability to make the appropriate calculations, and the ability to craft and design a model. Therefore, in accordance with our taxonomy, building a clock would relate to electrical engineering, mathematics, and mechanical engineering (from the greatest to the least significance).

It is important to note that not all actions can be sensibly tagged with a CIP code. This is especially true in areas of communication (e.g. playing alone vs. playing with friends). Nonetheless, the social aspects of Minecraft may be just as important as the correlation between in-game actions to STEM. Furthermore, non-STEM activities may play a mediating role in triggering interest: a player may enjoy the social aspects of Minecraft while working on projects, and then choose to become an expert in Redstone to promote these social goals (Redstone is a Minecraft version of electricity).

4. Method

As an initial evaluation of our Minecraft taxonomy and of the efficacy of our tags, we conducted a pilot study using two surveys: one for Minecraft, based on our taxonomy, and a second, previously developed STEM-attitudes survey. In this section we describe the study and report preliminary results.

4.1. Participants

In July 2017, we recruited 39 children participating in three, Minecraft-themed summer camps held at the Champaign-Urbana Community FabLab. The camps used Minecraft for different purposes, including to play group survival mode, 3D printing of Minecraft structures, and advanced topics (such as using mods, setting up servers, command blocks, etc.). Participants ranged in age from 9 to 15, and were all from the Champaign-Urbana, IL area. Based on survey responses, 9 were female (23%), 27 were male (69%), and 3 preferred not to answer (8%). In terms of ethnicity, 8 participants identified as Asian (21%), 2 as Hispanic (5%), 22 as White/Caucasian (58%), and 11 preferred not to answer.
(29%). In terms of experience with Minecraft, 2 said they were “new” (5%), 4 had played before and knew the basics (10%), 10 played “often” and for “hours at a time” (26%), 19 considered themselves experts (49%), and 4 said they play “way too much” and explore advanced topics often (10%).

4.2. Procedure

Upon arrival on the first day of each camp, parents were approached by researchers who introduced themselves and described the goals of the research. Children were then invited to participate in the research project if they chose to and their parents approved. Consent forms were given to the parents to read and sign. Researchers spent the first day of each camp getting to know the participants, observing their work, asking general questions, and helping whenever possible. At a designated time during each camp, two surveys were given to participants who had consented: the first survey focused on Minecraft play and the second on attitudes and interests in STEM topics. At later times, we interviewed selected campers to gain a better understanding of their interest in Minecraft and STEM.

4.2.1. Minecraft interest survey

We designed a 60-item survey by pulling a representative sample of items from the Minecraft action taxonomy (section 3), which currently has 166 leaf nodes (recall: leaf nodes represent game actions or activities). We chose items based on several criteria. First, we sought balance across the STEM disciplines, but also included other critical aspects of playing that were not directly STEM-related, such as playing with friends, decorating buildings, and combat-related activities. This opens the possibility to infer a more nuanced understanding of why children choose to play. Second, we attempted to include critical game activities that were somewhat core to game play (such as crafting, building, exploring, mining). Finally, for advanced activities (such as Redstone), we sought activities that were more common and likely to be recognized by a wider range of players. Some sample items and a screenshot of the survey is shown in Figure 3. Given our focus on middle school learners, we chose to use emoji rather than verbal descriptions for eliciting judgments. The selected set is based on research that these specific representations have been shown to have high reliability and appeal for children (Rounds, Phan, Amrhein, & Lewis, 2016). A big smiley represents “strongly like” and progressively less positive faces through to the tongue out emoticon represent “strongly dislike”. Participants were instructed to mark the middle item, “neither like or dislike”, for actions that they did not recognize.

* 2. Please rate how much you like each of the following Minecraft activities. 😊

<table>
<thead>
<tr>
<th>Activity</th>
<th>😊</th>
<th>😊😊</th>
<th>😊😊😊</th>
<th>😊😊😊😊</th>
<th>😊😊😊😊😊</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploring a brand new map.</td>
<td>😊</td>
<td>😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
</tr>
<tr>
<td>Exploring caves and finding new underground structures and resources.</td>
<td>😊</td>
<td>😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
</tr>
<tr>
<td>Playing in creative mode.</td>
<td>😊</td>
<td>😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
</tr>
<tr>
<td>Playing in survival mode.</td>
<td>😊</td>
<td>😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
</tr>
<tr>
<td>Building a safehouse or base for protection.</td>
<td>😊</td>
<td>😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
</tr>
<tr>
<td>Fighting off creepers, zombies, and other enemies.</td>
<td>😊</td>
<td>😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
</tr>
<tr>
<td>Building structures that could exist in the real world (Eiffel Tower, Sears Tower, bridges)</td>
<td>😊</td>
<td>😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
</tr>
</tbody>
</table>

Figure 3. Example survey items and interface (from SurveyMonkey).
4.2.2. **STEM attitude survey**

Participants also completed the Student Attitudes toward STEM survey (S-STEM), developed and validated by researchers at North Carolina State University as an attempt to capture attitudes that middle school and early high school students have towards STEM and 21st Century learning skills (Faber et al., 2013). Part 1 of the survey consists of subscales capturing learner beliefs about their abilities in key areas: math, science, engineering/technology, and 21st Century skills (e.g., “I am confident I can set my own learning goals”). Part 2 of the survey focuses on future interests of the learner – it provides short descriptions of 12 STEM-related fields (physics, environmental work, biology, veterinary sciences, mathematics, medicine, earth science, computer science, medical science, chemistry, energy, and engineering), and asks participants to rate from 1-4 how interested they are to learn more in that field. In our correlational analysis below, we refer to part 1 as “S-STEM beliefs” and part 2 as “S-STEM Future”.

4.3. **Results**

Here, we report preliminary analyses of our data by sharing results from each survey individually, followed by initial results that show modest correlations between STEM-related items (and sets of items) on the Minecraft survey with specific items on the S-STEM survey. At the time of this writing, we have not yet analyzed additional aspects of surveys, such as those related to gender, age, ethnicity, or Minecraft experience.

4.3.1. **Stated interest in Minecraft activities**

Unsurprisingly, participants in the study – generally experienced Minecraft players – positively rated many of the activities covered by the 60 items. Indeed, the mean rating across all items was 3.91 (with the highest rating scored as 5, and the lowest 1). Nonetheless, some notable differences do emerge from the data with respect to the relative scores between items. For example, as shown in Table 1, of the five highest rated items from the survey, two fall into the meta category (playing with friends and playing on a server), one in build-create-destroy (blowing things up with TNT), and two in the explore group (new maps and flying/viewing from high up).

4.3.2. **S-STEM**

Survey results also generally suggested that participant attitudes towards STEM fields and beliefs about their skills with respect to STEM were also positive. While responses to specific career-related questions were modest with respect to math (3.67) and science (3.54), participants responded very positively to questions related to creativity and engineering. Three of the five highest rated items were found in the Engineering & Technology portion of the survey (*):

- *I can get good grades in math* (4.28)
- *I like to imagine creating new products* (4.26)
- *Knowing how to use math and science together will allow me to invent useful things* (4.23)
- *When I have many assignments, I can choose which ones need to be done first* (4.13)
- *I would like to use creativity and innovation in my future work* (4.10)

The two lowest-rated beliefs of participants both had to do with science. They had less interest in pursuing a career in science (3.54) and were less sure they could do advanced work in science (3.51). We note that these are still positive scores. Interestingly, while students claimed to know how best to select assignments during homework (a metacognitive skill), they rated their ability to use time wisely far lower (3.64). Our current study lacks the power to determine if these are significant differences, however the differences are certainly worth of future investigation. Finally, in part 2 of the survey that focused on future interest, computer science and engineering were clear leaders (3.28
and 3.23, respectively, on 4-point scales), with veterinary and medical science coming in with the lowest ratings (2.31 and 2.28).

Table 1: Top 5 (blue) and bottom 5 (red) items from Minecraft survey (of 60 items total).

<table>
<thead>
<tr>
<th>Item (M)</th>
<th>Strong like</th>
<th>Like</th>
<th>No opinion</th>
<th>Dislike</th>
<th>Strong dislike</th>
</tr>
</thead>
<tbody>
<tr>
<td>Playing Minecraft with friends (4.62)</td>
<td>71.8%</td>
<td>23.1%</td>
<td>2.6%</td>
<td>0%</td>
<td>2.6%</td>
</tr>
<tr>
<td>Destroying things / blowing things up with TNT (4.44)</td>
<td>66.7%</td>
<td>15.4%</td>
<td>12.8%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Playing Minecraft on a server (4.41)</td>
<td>59.0%</td>
<td>30.8%</td>
<td>5.1%</td>
<td>2.6%</td>
<td>2.6%</td>
</tr>
<tr>
<td>Exploring a brand new map (4.36)</td>
<td>46.2%</td>
<td>43.6%</td>
<td>10.3%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Flying / viewing from high above the ground (4.36)</td>
<td>51.3%</td>
<td>35.9%</td>
<td>10.3%</td>
<td>2.6%</td>
<td>2.6%</td>
</tr>
<tr>
<td>PVP combat (3.41)</td>
<td>25.6%</td>
<td>25.6%</td>
<td>23.1%</td>
<td>15.4%</td>
<td>12.8%</td>
</tr>
<tr>
<td>Calculating and measuring distances when building a large structure (3.41)</td>
<td>5.1%</td>
<td>41.0%</td>
<td>41.0%</td>
<td>10.3%</td>
<td>2.6%</td>
</tr>
<tr>
<td>Watching Minecraft story videos (fiction) (3.08)</td>
<td>20.5%</td>
<td>25.6%</td>
<td>18.0%</td>
<td>12.8%</td>
<td>23.1%</td>
</tr>
<tr>
<td>Watching YouTube videos about combat (3.05)</td>
<td>20.5%</td>
<td>25.6%</td>
<td>18.0%</td>
<td>10.3%</td>
<td>25.6%</td>
</tr>
<tr>
<td>Building a calculator (3.0)</td>
<td>15.4%</td>
<td>18.0%</td>
<td>38.5%</td>
<td>7.7%</td>
<td>20.5%</td>
</tr>
</tbody>
</table>

4.3.3. Exploratory Factor Analysis (Minecraft survey)

To identify latent variables influencing the survey responses and compare them to our STEM categories (referred to as a “rational” approach), we conducted an exploratory factor analysis (EFA) on the Minecraft survey. We performed a principal components extraction with orthogonal rotation. A scree plot suggested 4 possible factors. We also suppressed cross-loadings less than .30, which are items that contribute to multiple factors simultaneously (thus might be double-barreled and candidates for removal in future surveys). We ran rotated factor loadings for 3, 4, and 5 factor solutions, but only report on the 4-factor solution here. Further, we present the cleaned version removing items that cross load.

Table 2 shows the factor loadings for the 4-factor solution with double-barreled items and items with lower factor loadings removed (space limitations prevent showing the full matrix). We note that this solution (as well as the 3- and 5-factor solutions) are likely to be very unstable and that more data are needed with the same items for the solutions to be admissible via proper EFA techniques and for there to be confidence in the scales that are generated. Nonetheless, we were interested in the factors that emerged. Component 1 seems to capture a great deal of the exploration, animal interaction, and farming/agriculture, and outdoor/nature aspects of our taxonomy (albeit with some noise). Component 2 seems to emphasize building and designing, while 3 (interestingly) combines redstone use (electricity and machine building) with combat/survival aspects of the game. There is no discernable theme for component 4, and it consists of the least number of contributing items.
Table 2: Items of 4-factor Component Matrix with largest factor loadings.

<table>
<thead>
<tr>
<th>Component</th>
<th>Item codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Brew-potion (.839), tame-animals (.812), fishing (.799), watch-sky (.786), craft-armor (.779), use-farming-tools (.778), find-npcs (.759), build-portal (.749), fly-with-elytra (.745), visit-biomes (.738), swim (.725), ride-animals (.719), create-storage (.693), collect-common-resources (.684), craft-weapons (.683), mining-resources (.672), hunt-with-bow (.666), spawn-animals (.635), plant-harvest (.625)</td>
<td></td>
</tr>
<tr>
<td>2 Build-real-buildings (.671), role-play-friends (.637), decorate (.601), plan-design-buildings (.590), build-fantasy-buildings (.573)</td>
<td></td>
</tr>
<tr>
<td>3 Build-complex-redstone (.647), fight-monsters (.596), use-redstone (.491), survival-mode (.468)</td>
<td></td>
</tr>
<tr>
<td>4 Build-irrigation-system (.598), creative-mode (.576), build-cannon (.489)</td>
<td></td>
</tr>
</tbody>
</table>

4.3.4. Cross-survey correlations

Our overarching hypothesis is that Minecraft play reflects underlying STEM interests of children who play, in part because the game models significant aspects of the natural and engineered world. Furthermore, our ultimate goal is to design Minecraft-based experiences that trigger interest in specific STEM areas (e.g., Astronomy). In this initial phase of the work, we seek to show connections between stated Minecraft and STEM interests. For example, we posit that a player who uses Redstone frequently is more likely to be drawn to mechanical engineering and electronics than one who focuses more on farming and interacting with animals in Minecraft (who we would predict would be more drawn to the agricultural sciences). As discussed earlier, we have attempted to articulate these connections through linking our Minecraft action taxonomy and STEM CIP codes. Viewing these links as hypotheses, we have completed an initial correlational analysis of our two surveys.

Using only the first coded tags of the items on the Minecraft survey, a Pearson correlation coefficient was calculated between the mean ratings of sets of MC-items of a given STEM tag and the corresponding relevant items on the S-STEM survey. For example, all items tagged as relevant to agriculture (AG) were checked for correlation with S-STEM items related to both general science beliefs and the specific future interest question for agriculture. All “sensible” correlations were run, and are displayed in Table 2. We note that this correlational analysis is only suggestive, and that our next step of analysis will be to run correlations between factors that emerge from our planned Confirmatory Factor Analyses on both surveys.

Table 3: Cross-survey Pearson correlation coefficients (NOTE: MC = Minecraft survey, ENG = Engineering, ANS = Animal Science, COMP = Computer Science, VETR = Veterinary Science)

<table>
<thead>
<tr>
<th>Minecraft items</th>
<th>S-STEM (Beliefs)</th>
<th>S-STEM (future interest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC-AG</td>
<td>ENG 0.126  MATH 0.437</td>
<td>_</td>
</tr>
<tr>
<td>MC-ANS</td>
<td>AG 0.023  BIO 0.433  CHEM 0.062</td>
<td>_</td>
</tr>
<tr>
<td>MC-ARCH</td>
<td>0.205</td>
<td>_</td>
</tr>
<tr>
<td>MC-MATH</td>
<td>-0.119</td>
<td>_</td>
</tr>
<tr>
<td>MC-CHEM</td>
<td>-0.109  0.241</td>
<td>_</td>
</tr>
<tr>
<td>MC-CIVE</td>
<td>0.033  -0.044  -0.044</td>
<td>_</td>
</tr>
<tr>
<td>MC-MECHE</td>
<td>0.171</td>
<td>_</td>
</tr>
<tr>
<td>MC-COMP</td>
<td>0.037  0.053</td>
<td>_</td>
</tr>
<tr>
<td>MC-GEOL</td>
<td>0.085  0.394  0.314</td>
<td>_</td>
</tr>
<tr>
<td>MC-PHYS</td>
<td>-0.095</td>
<td>_</td>
</tr>
</tbody>
</table>

4.4. Discussion

All of our observations require the caveat that this was only a small pilot study with a limited number of participants. The goal of this work is to begin to identify the links between Minecraft play and
STEM interest. We will use the pilot to refine the instruments and improve the accuracy and usefulness of the Minecraft taxonomy.

With respect to ratings of Minecraft activities, none of the top 5 activities are particularly surprising, however it is notable that combat-related items did not make the list. Interestingly, the highest rated items in our combat category were “build a safehouse” (4.26) and “craft armor and shields” (4.23), both of which fall into the protection (or “passive”) subcategory of combat. Based on the fact that 33 of our 39 respondents indicated at least that they were experienced Minecraft players with strong knowledge of the game, these results are most likely skewed towards the later stages of interest (in Minecraft, that is). In other words, novice players may find basic resource management and exploration more appealing until they emerge into more advanced topics. We will analyze our data along different experience dimensions in the future. Readers familiar with Minecraft are unlikely to be surprised by the high ratings for engineering and creativity found in the S-STEM survey. The links between creative aspects of STEM and Minecraft play are also worthy of further investigation.

Our initial EFA on the Minecraft survey suggested that 4 factors contributed to the survey results, with only 3 forming somewhat sensible groups. In particular, those related to the natural sciences, animal sciences, exploration, and agriculture fell into the first component. Our preliminary correlational analysis of both surveys suggested items and categories related to many of the same topics seemed to have the highest correlations with our S-STEM responses, although far more work and survey respondents is needed to reach confidence in this conclusion.

5. **Future work**

Our work seeks to elaborate on the links between Minecraft play and interest in STEM. Our overarching hypothesis is that video game play not only reflects interest in STEM, but influences it as well. We have reported our initial steps into investigating these questions and found modest relationships between some aspects of STEM and stated Minecraft preferences (mostly those revolving around agricultural, animal, environmental, and earth sciences). The ultimate goal of our research is to design informal learning experiences that trigger interest in STEM via specially designed Minecraft mods. In particular, we are development mods that represent hypothetical but scientifically valid versions of Earth (e.g., “What if the Earth had no moon?”). Using the tools developed in this pilot work, we will investigate whether exposure to such virtual worlds has the power to trigger interest in astronomy, astrophysics, and Earth science.

**Acknowledgements**

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**References**


