Exploring Student Engagement in an Augmented Reality Game

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Abstract

It has been argued that approaches to education should embed learning in activities that reflect the social and physical environments in which the knowledge is relevant. Only recently, did it become possible to situate learning in a variety of novel contexts using augmented reality (AR) games. This study investigates the behaviors of middle school students during their participation in an AR game called *Play the Past*. The findings of this study show that engagement differed during discrete activities in the game environment and that there was a relationship between the roles that students were assigned and their engagement.

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Introduction

Situated Cognition

In order to study how individuals learn it is necessary to consider how the activity, environment, and social processes interact to affect learning outcomes. Researchers studying situated cognition claim that these factors are integral to the learning process (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991), and have the capability to enhance or depress a person's ability to learn (Hendricks, 2001). Situated cognition research considers the context that learners experience and describes the interaction of knowing and doing that occurs as they complete cognitive tasks situated in authentic contexts (Brown, Collins, & Duguid, 1989). It involves thinking about the social dynamics and practices that learners engage in and how the environment guides those interactions. Theories of situated cognition highlight the social aspects of situated learning environments and explore the processes present at multiple levels of engagement (Lave & Wenger, 1991).

Brown, Collins, and Duguid (1989) argue that approaches to education should embed learning in activities that reflect the social and physical environments in which the knowledge is relevant. They focus on how learners experience concepts and ideas as tools that are best understood as interconnected experiences that include social dynamics and can be supported via scaffolding activities incorporating cognitive apprenticeship practices. Technology offers multiple mechanisms to support these types of situated learning experiences. It enables researchers, educators, curriculum, and game designers to situate students' educational activities in their physical environment. Technology can also support interactions and direct learner behaviors so that students are able to participate in activities individually and collaboratively. Technology based games are incorporating augmented reality (AR) to support situated learning experiences.

Augmented Reality

Today more than ever, it is possible to situate learning in meaningful ways by using new technologies, such as, AR games. In general, AR addresses the major facets of situated learning by providing meaningful context and supporting social interactions. AR further supports learning by helping students to engage in high level cognitive activities such as "authentic inquiry, active observation, peer coaching, reciprocal teaching and legitimate peripheral participation with multiple modes of representation" (Dunleavy, et al. 2009).

Augmented reality is defined as a "real-time direct or indirect view of a physical real-world environment that has been enhanced by adding virtual computer-generated information to it" (Hugues, Fuchs, & Nannipieri, 2011) that can apply to all senses (smell, touch, hearing, visual, etc). Thanks to these affordances, AR has the potential to significantly enhance learning environments, especially when combined with the engaging qualities of digital games. AR games are defined as, "…games played in the real world with the support of digital devices (PDAs, cell phones) that create a fictional layer on top of the real world context…" (Jan & Squire, 2007, p. 6).

Augmented reality is often used to enhance students' learning and engagement in informal learning contexts like museums. In a study of using AR with middle school students in a science museum, Yoon and colleagues (2012) investigated how different combinations of scaffolds and AR approaches supported student learning. They found that students were able to increase their conceptual understanding by engaging in augmented learning activities alone, but required support in order to develop a more advanced understanding of the target concepts (Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012).

In their (2007) case study, Squire and Klopfer show that students who participate in an AR learning environment engage in scientific practice as a social endeavor involving inquiry activities and problem solving. They suggest that AR simulations provide an authentic alternative for teaching environmental science and engineering. The current work follows this trend by examining students' behaviors in an AR simulation with a history focus. History is an area of education that can greatly benefit from instructional methods that move beyond memorizing isolated dates and facts.

The current study focuses on the relationship between the roles that students play in an AR environment and their levels of engagement. While AR has the capacity to increase students' feelings of immersion and engagement (Bronack, 2011), it is not reasonable to presume that all students experience these affordances. In this manuscript, the authors investigate whether there are differences in engagement based on the design of the activities within AR games.

Design Principles for AR Games

AR games make it possible to situate learning in a relevant and engaging environment, leverage social processes, and create engaging activities. For example, Dunleavy, Dede, and Mitchell (2009) created an AR game that allowed students to investigate the crash landing of an alien spacecraft, while learning a variety of math and science concepts. Although there were some caveats and limitations to the implementation of this game, students who went through this experience were highly engaged and wanted to learn more to solve the mystery. Klopfer, Perry, Squire, and Jan's (2005) study found that the types of roles that students took on in the AR environment affected their level of engagement. Specifically, they found that higher interdependence and interaction between distinct roles increased collaboration and engagement.

Recently, three additional design principles for learning in AR games were established by Dunleavy (2014). He established these principles in order to enhance the unique capabilities of AR and minimize the weaknesses of the technology. The first design principle he states, is that AR learning experiences should "enable and then challenge", which means that users in these environments should be acclimated to the experience and then challenged with more complex tasks. For example, in the AR game, Dino Dig (http://www. Playfreshair.com/), players are given tasks of increasing complexity starting with navigating to a location, then gathering information, and finally completing a challenge or interacting with another player. This principle has also been employed in several other AR games, including *Zoo Scene Investigators* (Perry, Klopfer, & Norton, 2008), where the complexity of the game was slowly increased, and *Environmental Detectives* (Klopfer & Squire, 2008) that implemented scaffolding at each step of the game, to ensure students were able to achieve the optimum learning experience.

Second, Dunleavy (2014) advocates for AR learning experiences to be, “driven by gamified story”, meaning that the rationale and motivation for the experience should be driven by a story. This design principle has been leveraged in several of the games mentioned above, including *Alien Contact!*, *Environmental Detectives*, and *Zoo Scene Investigators*. For instance, *Alien Contact!* Provides a compelling narrative, where “aliens have crash landed near the students’ middle school”, and the students must investigate why the aliens have come to their planet (O’Shea, Mitchell, Johnston, & Dede, 2009).

Third, Dunleavy (2014) recommends that learning experiences in AR should allow the users to, “see the unseen”, which is an inherent capability of AR, because information can be overlaid on the physical world. This design principle is exemplified by an exhibit at the *San Diego Zoo,* where students learn about the anatomical composition of animals at the zoo, which is enhanced by AR. In this exhibit, students are given a mobile device that they can use to scan signs at the zoo, which once scanned will present a 3-dimensional model of the animal represented on the sign. This is just one example of this design principle in action though.

Current Study

Based on these design principles, and studies on the effectiveness of several other AR games, it is clear that they have the potential to enhance learning and engagement by situating it in activities that are relevant, meaningful, and social. However, the detailed behaviors of students in AR games has not been extensively studied. To complement this body of research, the current study investigates the behaviors of students that reflect situated learning and engagement while playing an AR game called *Play the Past*. Students play this game during field trips to the Minnesota History Center.

Play the Past provides a game-based learning experience for middle school students where they are presented tasks to accomplish via historically and socially meaningful scenarios. Game-based learning refers to learning in a gameplay context where learners solve problems that are presented in scenarios (Ebner & Holzinger, 2007). All the information and materials are situated and interwoven into game scenarios and there are usually storylines in which learners as players are presented with problems to solve. As students progress through *Play the Past*, they assume different roles in a narrative that guides them to explore history in an engaging and fun way. The game is divided into three hubs (Sod House, Fur Trade, and Iron Mine), that are located within specific areas of the *Then Now Wow* exhibit, where students must master different roles (Hunter, Clerk, Iron Miner, Farmer), and interact with other students to master tasks and complete levels.

The majority of the design principles mentioned above are stable across the hubs in *Play the Past*, including the need to scaffold the learning experience (Klopfer, Squire, 2008; Dunleavy 2014; Perry et al., 2008), the use of narrators as guides (Dunleavy, 2013), and the AR game providing the user with the ability to "See the Unseen" (Dunleavy, 2014). However, students take on very different types of roles in each of the hubs within *Play the Past*, that promote different levels of interdependence and interaction (Klopfer et al., 2005). The Sod House is primarily a single-player narrative game, where students interact with a narrator to complete different tasks that were relevant to someone living on the prairie in the 19th century. The Iron Mine is primarily a single-player game as well, but a narrator encourages the student to work with others to complete shared tasks. For instance, students in the Iron Mine must learn how to efficiently earn money by mining with different tools, and they can complete this alone or in tandem with other players. The Fur Trade is the only true multi-player game that requires interdependence and interaction between students, because each student is assigned to one of two distinct roles (Clerk or Hunter) that must trade goods with each other to complete the hub. Table 1 summarizes the *Play the Past* hubs, player roles, and gameplay activities. In the current study, the authors examine whether students exhibit different levels of engagement based on the hub they are interacting in and the role they are assigned. Our work poses two main hypotheses.

Hypothesis 1. Levels of Engagement. Based on the design principle proposed by Klopfer and colleagues (2005), which states that higher interdependence and interaction between distinct roles increases collaboration and engagement, the authors hypothesize that students will be most engaged with the Fur Trade, then the Iron Mine, and the least engaged with the Sod House.

Hypothesis 2. Effect of Role on Engagement. Due to the difference in the scaling of complexity between the two roles in the Fur Trade hub, the authors hypothesize that students who are assigned to be hunters will have a higher level of engagement with the game than students who are assigned to be clerks, because the “enable and then challenge” (Dunleavy, 2014) principle may have been violated for students playing the game as clerks.

Methods

Study Design

This study investigates the behaviors of middle school students during their participation in an AR game called *Play the Past*. The study primarily employs an observational design to draw inferences about how subjects are affected by exposure to an environment or intervention (Carlson & Morrison, 2009; Tooth, Ware, & Bain, 2005). This design allows us to conduct secondary data analyses to explore the multiple pathways that students experience as they participate in the AR game. In this study, data analyses are performed on telemetry data collected by the iPod Touch used by each student. Telemetry data is commonly used to study the behavior of large samples of people who play digital games (Gagne, El-Nasir & Shaw, 2012).

Participants

The sample for this study consists of 7,129 4th to 6th grade students from 95 urban elementary schools in the upper Midwest. The students participated in *Play the Past* between September 1, 2014 and June 3, 2015.

AR Environment

Play the Past is embedded in the Minnesota History Center's *Then Now* Wow exhibit, which is focused on several different periods of Minnesota history. It is divided into hubs (Sod House, Fur Trade, and Iron Mine), that are located within specific areas of the exhibit, where students must master different roles (Hunter, Clerk, Iron Miner, Farmer) and tasks to complete levels. Each hub includes QR (Quick Response; Mu, Topolewski, & Scholz, 2008) codes on artifact surfaces, which students scan with their iPods (Figure 1) to progress through levels in each hub. This type of interaction that relies on location, qualifies *Play the Past* as a location-based AR game according to Cheng and Tsai's (2013) definition. Each of the hubs has two levels that the student must progress through to complete it. As they play, students are randomly assigned different roles and participate in three hubs.

Procedure

All of the students who participated in *Play the Past* were on a field trip at a state history center with their class. Each class included between ten and forty students. Students spent approximately 38.3 (SD = 7.17) minutes in the game (Figure 2). During their participation, students had access to peers, chaperones, teachers, and museum staff for help navigating the simulated environment.

Upon arrival at the museum, students were introduced to the iPod and how to use it to participate in the game. After the short orientation, students were allowed to explore the exhibit with their classmates and play the game by themselves or in groups. Students were allowed to explore and complete the different hubs and levels as they pleased, which is exemplified by Figure 3. This image shows that students took a variety of pathways through *Play the Past*.

The current study mainly focuses on students' experiences in the Fur Trade hub, because it is the only hub where students assume distinct roles that require them to interact with each other. This hub includes roles that promote positive interdependence, interaction, and individual accountability. These design features should encourage higher levels of engagement. In the Fur Trade hub, students are randomly assigned to one of two roles. Each role has distinct tasks and goals. Roughly half of students are assigned to be hunters. Their tasks involve helping Monsomanain, an Ojibwe hunter, to gather beaver pelts to trade for goods. The other half of students are assigned to be clerks. Clerks assist John Sayer, a company clerk, who need to make a profit from trading their European goods for beaver pelts. Once students are assigned roles, the game guides them to gather their supplies and negotiate trades. In order to make a trade, each student must identify another player to trade with and negotiate with them. For example, a hunter would need to find a clerk and negotiate the purchase of a European good from them, which the hunter would pay for with their beaver pelts that they gathered. Once the students agree on the trade, both parties must confirm the trade of goods through the AR game. The Fur Trade hub is divided into two levels that are described in detail below:

Level 1. As described above, students are assigned different roles where they help a hunter or a clerk. In order to complete Level 1, students helping the hunter must "trap" eight beaver pelts by scanning QR codes on beaver floor tiles to prepare for trading. Students helping the clerk must use ten beaver pelts provided on credit from the Fur Company in Montreal to stock their store. These are individual tasks that do not require interaction between students.

Level 2. During Level 2, students use the goods and supplies they obtained in Level 1 to trade with each other. They negotiate their trades in real time using their iPods. Hunters complete Level 2 by successfully negotiating fur trades for at least five European goods. Clerks finish Level 2 by successfully completing fur trades for at least 15 beaver pelts, which results in a profit of five beaver pelts. The activities at this level promote interdependence, prompt discussions, and generally lead to more interactions between students.

Data Collection

The *Play the Past* application collected data from each student through their iPods. All data was sent to a secure Structured Query Language (SQL) database. The following types of events were recorded; QR codes scanned, web pages viewed, videos watched, levels completed, wages earned, and interactions with exhibit artifacts. Each of these events was tagged with a timestamp, user identification number, and group identification number (Table 2). On average, each student had 225 events logged during their visit.

Results

Hypothesis 1. Levels of Engagement

To determine whether students were equally engaged with each of the hubs in *Play the Past*, the authors computed completion rates for Level 2 in each hub that are plotted in Figure 4. The authors hypothesized that the Fur Trade would have the highest level of engagement, because it has roles that promote positive interdependence, interaction, and individual accountability. Based on this data visualization, it is clear that students were more engaged with the Sod House and Iron Mine, and did not fully engage with the Fur Trade hub, which provides evidence against the hypothesis. However, this trend is not present at earlier levels in each hub (Start, Level 1; Table 3), which means that students have similar levels of engagement across hubs until they reach Level 2.

Hypothesis 2. Effect of Role on Engagement

The authors were able to look at how student roles (Clerk and Hunter) affected engagement levels by further analyzing student behaviors in the Fur Trade hub. Of the 7,129 students who participated in the AR game, 5,772 students completed Level 1 in the Fur Trade, which enabled them to trade with each other. Among the 5,772 students who completed Level 1, 3,038 students were assigned to be hunters and 2,734 students were clerks, which is a significantly smaller number of clerks ($\chi^2 = 16.01$, *df* = 1, *p* = <.001). Unfortunately, this trend continues in Level 2, where only 1,208 clerks complete Level 2 in comparison to 1,842 hunters ($\chi^2 = 131.78$, *df* = 1, *p* = <.001). These findings suggest that there may be an imbalance in the design of the game between roles. However, this information does not provide us with information as to why there is a discrepancy in engagement between these two roles.

To investigate this trend further, the authors focused on the specific behaviors of students in the Fur Trade. In particular, the authors focused on their interactions with the trading mechanic. This is the core activity that students must use to complete Level 2. To operationalize trading efficacy, the authors calculated a trade ratio for each student to reflect their skill at negotiating trades. For example, if a hunter paid 1 beaver pelt for an item that was worth three beaver pelts, the hunter would receive a trade ratio score of 3 for this trade. In contrast, if a clerk were to sell an item that was worth 4 beaver pelts for 1 beaver pelt, they would receive a score of $\frac{1}{4}$ for this trade. An average of the trade ratio scores was calculated for each player and used as a reflection of their trading skill (Table 4).

A mixed-effects logistic regression was used to explore the relationship between role, trade ratio, and Level 2 completion rate. There was a significant interaction effect in Model C between Role and Trade Ratio when predicting completion of the levels within the Fur Trade (Table 5), because Model C had the lowest corrected Akaike Information Criterion (AICc; Akaike, 2011) in comparison to Model A and B.

To help interpret these findings, the authors plotted the predicted probability of completing Level 2 of the Fur Trade (Figure 5). This figure shows that students who are assigned to be clerks have a lower probability of completing Levels 1 and 2 than students who are assigned to be hunters when they have an average trade ratio lower than 6. However, the largest discrepancy in probability of Level 2 completion occurs when students have an average trade ratio between 0 and 2, which results in clerks having roughly 15% lower probability of Level 2 completion than hunters.

Conclusion

Based on the findings of this study, it is clear that engagement levels differed between the hubs and levels in *Play the Past*. Students were more engaged with the Iron Mine and Sod House hubs, despite the Fur Trade's design to that had distinct roles that promoted positive interdependence and interaction. This finding disproved our first hypothesis that students would be the most engaged with the Fur Trade hub, based on prior research conducted by Klopfer and colleagues (2005). This contradictory finding may have been a result of a design problem with the roles (Hunter or Clerk) that were assigned to students in the Fur Trade. To better understand why this trend was occurring, the authors investigated the behavior of students within the Fur Trade during Level 2 to determine if there were specific problems with the design of the game that could help us explain the lower level of engagement.

Our results show that the design of the roles employed in the Fur Trade (Clerk and Hunter) do not pose equally difficult challenges. Specifically, the students assigned to be a clerk must trade at a much higher profit margin than students who are assigned to be a hunter, which may impede them from finishing Level 2 or encourage them to quit the Fur Trade and move to the Sod House or Iron Mine. Conversely, students who were assigned the role of hunter, were more likely to complete the Fur Trade than students who were assigned to be clerks. Based on this trend, it is clear that students who had distinct roles were not equally engaged in the game, despite the roles being designed to support collaborative learning by promoting positive interdependence and interaction, as suggested by Klopfer and colleagues (2005). In addition, these findings suggest that the inclusion of interdependent roles may interact with other game design elements, such as difficulty in ways that are not beneficial to the student experience, and impede collaborative learning within the environment.

To remedy this discrepancy and increase the number of students engaging with the Fur Trade, the design of the game should be updated to balance the difficulty of the clerk and hunter roles. Specifically, the game could provide the clerks with more in-game assistance and scaffolding, which aligns with the design principle utilized by several other AR games (Perry, Klopfer, & Norton, 2008; Klopfer & Squire, 2008). For instance, if clerks were given a more detailed example on how to trade for a profit, they may not have as much trouble with the task. Admiraal, Huizenga, Akkerman and Ten Dam (2011) highlight the necessity of this type of challenge-skill balance in order for students to experience high levels of engagement during gameplay.

In addition to the practical application of the results from this study to improve the design of *Play the Past*, it also serves as an example of how to investigate engagement among students in an AR game to improve their experience. All too often, the behavior within a game is overlooked as researchers strive to understand how playing a game affected learning outcomes and test scores (Gee, 2003). Although this trend is improving (Clark, Tanner-Smith, & Killingsworth, 2014), it is worth reiterating that it is very important to investigate how students are interacting within these environments so that the student experience, their ability to learn, and engage can be improved. The current study contributes to the growing trend to explore log data and engage in learning analytics to understand how interactions in these rich contexts contribute to learning.

Limitations

Although the findings presented here are rigorous and thorough, there are several limitations. First, due to an unfortunate limit on the data that could be collected, there is no information regarding the individual students' age, gender, or socioeconomic status. All of these variables may have had an impact on our findings. For instance, the students who completed Level 2 of the Fur Trade may have been composed of primarily 6th graders, while those that did not complete Level 2, may have been in 4th or 5th grade. Similarly, students from lower socioeconomic statuses may have struggled with *Play the Past*, because they may not have as much access to mobile technology, such as, iPods or smart phones.

Illustrations

Table 1.
Summary of the hubs in Play the Past.

Hub	Interaction Type	Gameplay Description
Sod House	Individual	Students interact with a narrator to complete different tasks that were relevant to someone living on the prairie in the 19th century. To complete this hub, students must make several decisions about how to manage their prairie effectively.
Iron Mine	Individual	Students in the Iron Mine must learn how to efficiently earn money by mining with different tools. To complete the hub, each student must earn $2.00.
Fur Trade	Collaborative	Each student is assigned to one of two distinct roles (Clerk or Hunter) that must trade goods with each other. To complete the hub, a clerk must trade their goods to earn 15 beaver pelts, while a hunter must buy 5 European goods with their beaver pelts.

Table 2.
Telemetry data sample.

Group Number	Player ID	Timestamp	Event	Event Type	Event ID
5252-75253	53445	3/13/15 16:51	53445 scanned Beaver Pelt.	ENTER_QRCODE	NA
5252-75253	53445	3/13/15 16:51	53445 viewed Beaver Pelt (Web Page).	VIEW_WEBPAGE	3718
5252-75253	53445	3/13/15 16:51	53445 received 1 Beaver Pelt (Item).	PICKUP_ITEM	47029
5252-75253	53445	3/13/15 16:51	53445 scanned Beaver Pelt.	ENTER_QRCODE	NA
5252-75253	53445	3/13/15 16:51	53445 viewed Null (Web Page).	VIEW_WEBPAGE	3731
5252-75253	53445	3/13/15 16:51	53445 received 1 Knife (Item).	PICKUP_ITEM	50188
5252-75253	53445	3/13/15 16:51	53445 lost 1 Beaver Pelt (Item).	DROP_ITEM	47029
5252-75253	53445	3/13/15 16:51	53445 received 1 Hoe (Item).	PICKUP_ITEM	50181
5252-75253	53445	3/13/15 16:51	53445 lost 4 Beaver Pelt (Item).	DROP_ITEM	47029
5252-75253	53445	3/13/15 16:51	53445 received 1 Gunpowder (Item).	PICKUP_ITEM	49584

Table 3.

Table of student completion numbers across levels and hubs in Play the Past.

	Fur Trade	Iron Mine	Sod House
Start	6,640	6,968	6,840
Level One	5,772	5,751	5,453
Level Two	3,049	3,916	4,248

Table 4.

Description of trade ratio scores between clerks and hunters across levels completed in the Fur Trade.

		Level 1			
	Clerks	Hunters	*t*	*df*	*p*
N	1,128	789	9.78	2012	>.001
Trade Ratio Average (SD)	3.26 (2.93)	.58 (.62)			
Trade Ratio Range	.91-24	0-6			
		Level 2			
N	1,195	1,835			
Trade Ratio Average (SD)	4.01 (4.59)	.74 (.47)	10.33	3159	>.001
Trade Ratio Range	.7-75.18	.06-9			

Table 5.
Taxonomy of Mixed Effects Logistic Regression Models Fitted Using BOBYQA to Explain Variation in Fur Trade Completion Rates for 4,947 Students.

	Model A	**Model B**	**Model C**
Fixed Effects	Estimate (SE)		
Intercept	.38 (.09)	1.99 (.14)	1.08 (.20)
Trade Ratio	-.01 (.01)	.11 (.02)	1.43 (.22)
Role		-1.26 (.08)	-.77 (.11)
Role x Trade Ratio			-.67 (.11)
Random Effects	Estimate (SE)		
Group	.54 (.73)	.68 (.82)	.69 (.83)
Measures of Model Fit			
Log-likelihood	-3,147.72	-3,008.63	-2,988.02
AICc	6,301.45	6,025.26	5,968.04

Figure 1. Image of a student scanning a QR code in the Fur Trade.

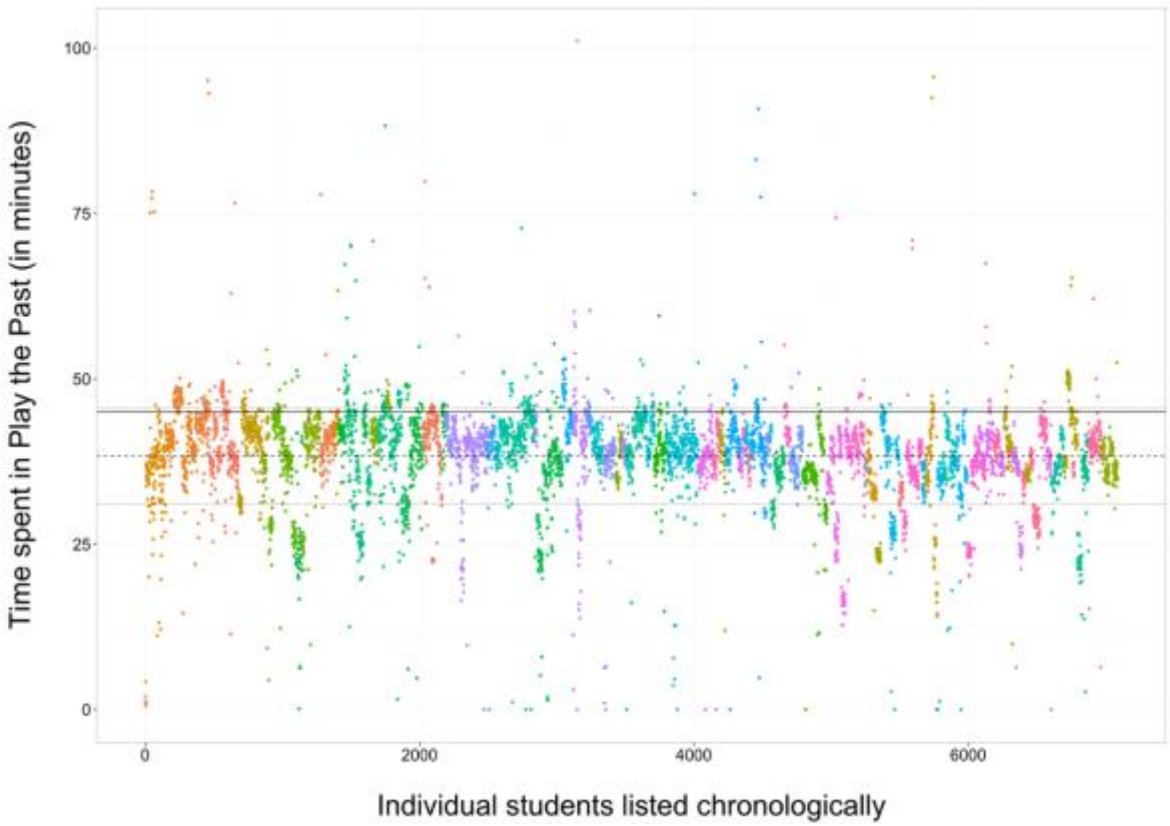

Figure 2. Scatter plot of time spent in *Play the Past* by each student.
Note: Colors indicate different classes.

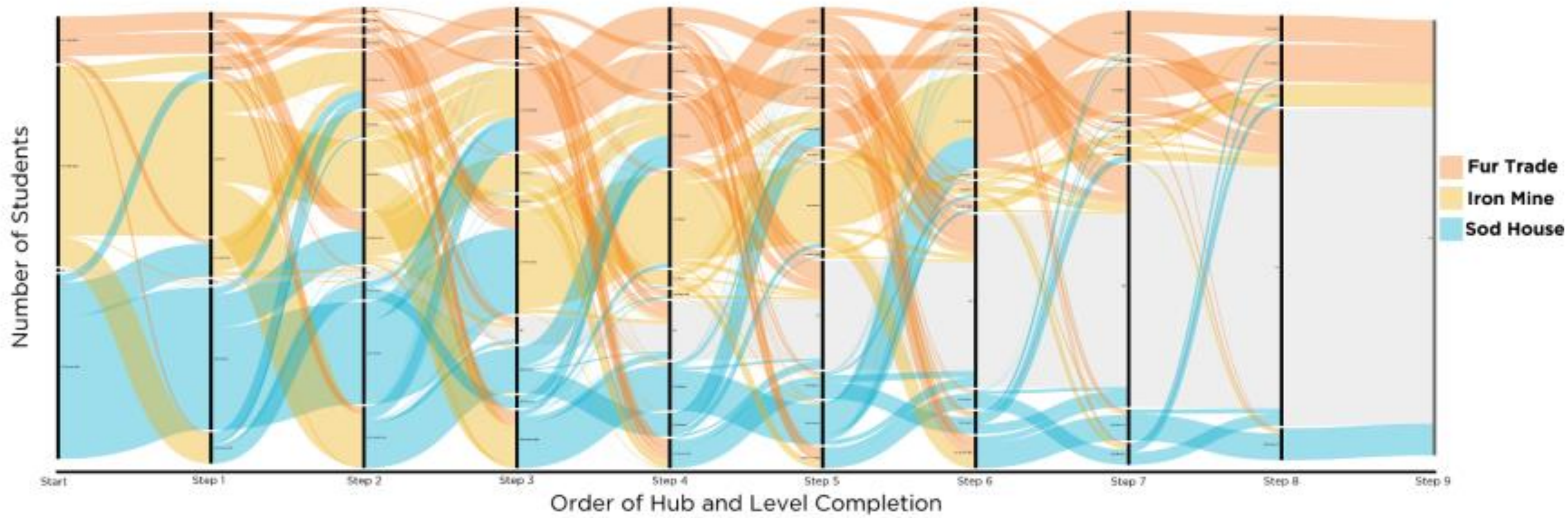

Figure 3. Alluvial plot of student hub and level completion in *Play the Past*.

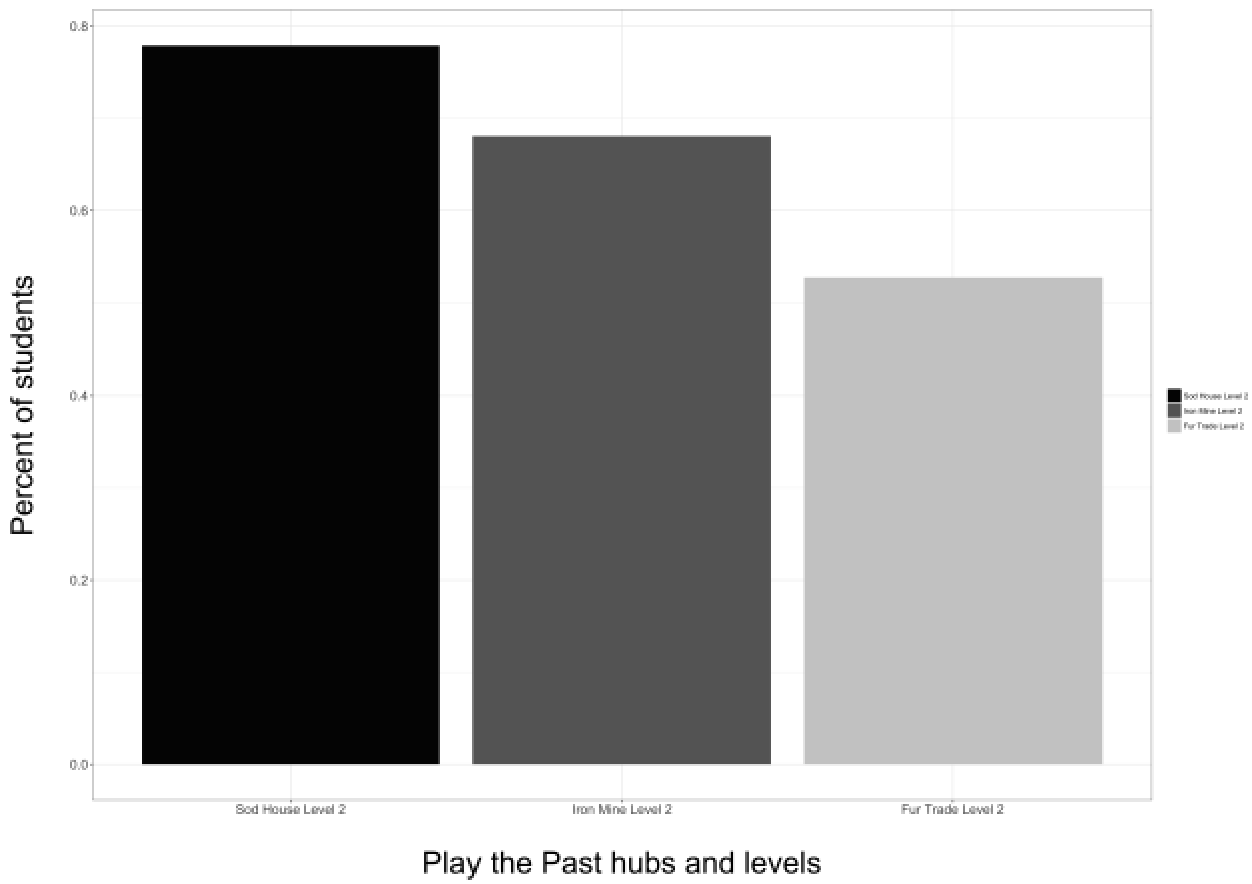

Figure 4. Bar plot of level 2 completion rates across hubs in *Play the Past*.

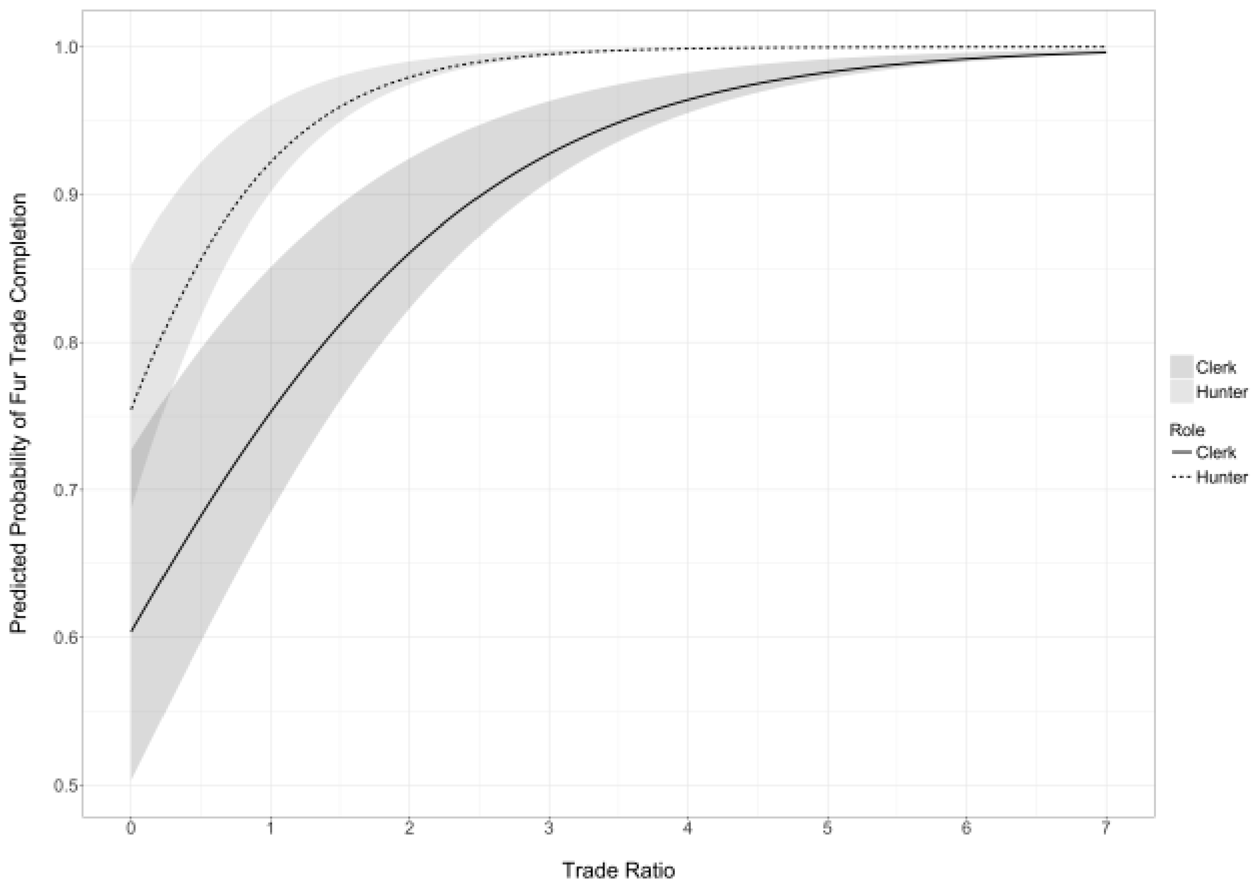

Figure 5. Predicted probability of Fur Trade completion based on Trade Ratio by Role in *Play the Past*.

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