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The Interplay Between In-game Activity, Learning Gains, and Enjoyment in a Serious Game on STEM

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ABSTRACT

The exponential growth of technology is transforming most existing sectors in the world. One of the technologies that are impacting significantly our society is video games, which have become a new cultural form of expression. Moreover, the research suggests that especially within educational contexts they present great learning opportunities. However, little is known in serious games about the interplay of the in-game activity, learning gains, and enjoyment with the game. Therefore, in this chapter, the authors use data from a pilot study conducted with a STEM inquiry-learning serious game to compute behavioral metrics and analyze their relationship with the learning gains and enjoyment of students based on survey responses. We report exploratory results of the different metrics and correlation analysis to analyze the interplay between these three sets of metrics. This work will exemplify the potential that learning analytics approaches and serious games have to transform education and training across contexts.

Keywords: Serious Games, Learning Analytics, Game-based Learning, Educational Technology, Artificial Intelligence, Technology-enhanced Learning, STEM Education, K12 Education.

INTRODUCTION

The exponential growth of technology is transforming most existing sectors in the world, increasing the performance and potential applications that in the past no one thought could be real (L. M., Madhushree and R., Revathi and Aithal, 2019). One of the sectors that is being importantly impacted is the educational one, where the incorporation educational technologies is helping improve the quality of the learning process, facilitating the work of instructors and enhancing the education received by students (Dabbagh et al., 2016; Thomas, 2016). Within these educational technologies, there are multiple directions in the literature, and within this chapter, we focus on the potential of video games within educational contexts (Squire, 2011).

The importance of video games in our society has also raised significantly during the last decade. Video games have become a new cultural form of expression and are impacting everyday life such as consumption, communities and the identities of the individuals that belong to a society (Daniel & Garry, 2018). Moreover, they are becoming very widespread, and all kids are growing up playing video games, with will change the future generations where video games will become a native medium. Also, the perceptions regarding video games are changing, as 74% of American parents believe that video games can be educational for their children, and 57% also play video games with them (ESA, 2019). Therefore, video games are going further beyond mere entertainment purposes and are deeply penetrating society at different scales and for multiple purposes (Muriel & Crawford, 2020).

Within educational contexts, video games have been one of those educational technologies that have become trendier over the last decade. Several authors have addressed the benefits of game-based learning, as games can represent more interactive scenarios that players can inhabit, adapting to a set of rules and constraints, to accomplish an established objective after surpassing a series of challenges (Gee, 2003, 2008; Prensky, 2006); this resembles much more realistically real-life situations than other more passive mediums like the ones that learners are usually exposed during traditional education. In fact, several literature reviews have shared very positive insights about the use of games for education, for example for the acquisition of 21st century skills (Qian & Clark, 2016) or for learning math (Divjak & Tomić, 2011). However, games are still scarcely used for educational purposes, and little is known yet about why games work and in which cases they might not be good options.

More specifically, in this chapter, we want to better understand the relationship between the activity that students perform within the game based on in-game metrics, the learning gains that students experience after playing the game, and the enjoyment during this activity. This can help better understand the interplay between these three important cornerstones of the implementation of games in the classroom (Wang, Nguyen, Harpstead, Stamper, & McLaren, 2019). To do so, we use data from a pilot study conducted with Radix, an inquiry-learning STEM game that was tested across US schools. We will use in-game data from this game to compute behavioral metrics and analyze their relationship with the learning gains and enjoyment of students based on survey responses before and after interacting with Radix as part of their algebra sessions in their school. More specifically, this chapter has the following two objectives:

1. To perform an exploratory analysis of the results of a pilot study with Radix on algebra contents with several classes across the US.
2. To perform a correlational analysis to analyze the interplay between the in-game metrics, the learning gains, and the levels of enjoyment.

The rest of the chapter is organized as follows: Section 2 presents a background on educational technologies, serious games, and learning analytics. Section 3 depicts the methodology that we have pursued to reach our objectives and Section 4 describes the results for each one of the objectives. We finalize the paper with discussion and future work directions, and a conclusion in Sections 5 and 6 respectively.

BACKGROUND

We can find in the literature a broad spectrum of studies that can be categorized within the scope of technology-enhanced learning. First, we have specific educational software, such as learning management systems that have become the norm during the last decade (Muñoz Merino, Delgado Kloos, Seepold, & Crespo García, 2006), intelligent tutoring systems that provide smart environments to learn specific topics (Anderson, Boyle, & Reiser, 1985), simulations (Dameff, Selzer, Fisher, Killeen, & Tully, 2019), virtual (Pan, Cheok, Yang, Zhu, & Shi, 2006) or augmented reality (Ke & Hsu, 2015), and many other types of interactive learning environments that can take very diverse forms (Renkl & Atkinson, 2007), and where we can include video games, which is our focus (De Freitas, 2006). Moreover, there have also been several hardware trends that are attempting to perform a boost in the devices used for educational purposes, such as mobile devices (Ke & Hsu, 2015), wearables (Cain & Lee, 2016), smart glasses (Holstein, McLaren, & Aleven, 2017), or sensorized smart classrooms (Prieto, Rodríguez-Triana, Kusmin, & Laanpere, 2017) across others cutting-edge technologies.

Finally, one of the most notorious research directions in technology-enhanced learning has been on the development of data-intensive applications for different purpuses, such as adaptive learning to personalize the contents based on the current status of a student (Magnisalis, Demetriadis, & Karakostas, 2011), data visualization dashboards that can be used by instructors to track the progress of the students or used by students for self-awareness purposes (Charleer, Santos, Klerkx, & Duval, 2014; Park & Jo, 2015), automatic actuators that can include early warning systems to detect students at risk (Delen, 2010) or recommendations systems that can send suggestions to students (Dwivedi & Bharadwaj, 2015), or student behavioral modeling in order to understand how are the students interacting with the learning environment (Muñoz-Merino, Ruipérez Valiente, & Kloos, 2013), which is the kind of analysis that we conduct. These are only some examples of the new advances in this domain.

In terms of interactive learning environments, we focus on video games. There have been numerous advocates of game-based learning, some of them indicating that the foundations are quite different from other forms of learning and they should be conceptualized with different frameworks and design approaches (Plass, Homer, & Kinzer, 2015). Multiple authors have performed meta-reviews on game-based learning concluding that even though, the benefits are notorious, one needs to pay careful attention to the design, the motivation of the learners, and the many contextual factors (De Freitas, 2006; Divjak & Tomić, 2011; Qian & Clark, 2016). However, serious games might also have other purposes than learning, for example motivating users to take care of their health (Baranowski et al., 2016). Therefore, the purposes that serious games can are broader than those of educational games. One of the key features of all these games is that they can increase the engagement and enjoyment that users experience during the activities when compared to other more traditional settings (Callaghan, McShane, & Eguiluz, 2014). However, little is known regarding the relationship of this enjoyment with what users do within the game, and in this chapter, we go beyond the state of the art by analyzing the interplay between in-game metrics and enjoyment.

A common approach to analyze the impact that these educational technologies can have on the learning process is the implementation of learning gains, which are often computed based on the difference between a pre-test performed before conducting the interactive activity and a post-test after finishing the activity (Vermunt, Ilie, & Vignoles, 2018). This is a common approach in the literature, and researchers have measured learning gains after playing a game (Wang et al., 2019), interacting with a Khan Academy course (Ruipérez-Valiente, Muñoz-Merino, & Kloos, 2018), or conducting tasks within an intelligent tutoring system (Kochmar et al., 2020), among many other examples. In our study we also perform this approach by computing the learning gains after playing with Radix, moreover, we go beyond the state of the art by connecting these learning gains with the in-game behavioral metrics.

Finally, our work can be framed within the area of learning analytics, which was previously defined as the "measurement, collection, analysis, and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" in the First International Conference on Learning Analytics & Knowledge in 2011. Our work draws from techniques in this field in order to model the behavior of the learners with the game. For example, other studies have also used learning analytics in games to build visualization dashboards to support the instructors in the classroom (Jose A. Ruiperez-Valiente, Gomez, Martinez, & Kim, 2021), to perform a game-based assessment of creativity (Yoon J Kim & Shute, 2015), or other content constructs like first aid and resuscitation skills (Charlier, 2011), to adapt a game based on the previous behavior of the users (Peirce, Conlan, & Wade, 2008), or to detect sequences of errors in a geometry game (Gomez, Ruipérez-Valiente, Martínez, & Kim, 2021), among many other potential examples. However, to the best of our knowledge, this is the first study in games that combines learning analytics in-game metrics with enjoyment and learning gains to analyze the interplay between these three cornerstones. Here lies the main contribution of this chapter with respect to the current literature.

METHODOLOGY

In this section of the chapter, we describe the methodology that we have pursued to analyze the interplay between in-game metrics, enjoyment and learning gains. Figure 1 shows an overview of the methodology that we will describe in detail in the following different subsections.

Figure 1. Overview of the methodology pursued in this study.

The Radix Endeavor Serious Game

The Radix Endeavor is an inquiry-based, multidisciplinary, MMO-style online game for STEM learning that includes a balance of guided tasks and open-ended exploration. It is inquiry-based in the sense that in it, players solve problems by exploring a topic, figuring out what questions need to be asked, and determining a pathway to answer those questions. It is an MMOG-style in that it involves players controlling an avatar in a third person perspective, is set in a virtual multiplayer world that is open-ended, and includes set sequences of tasks for players to work through as they explore the world and build conceptual understanding. It was developed at the MIT Education Arcade (see videos in the YouTube channel[1]), was launched in January 2014, and was free to play. Radix is aligned with the Next Generation Science Standards for biology and the Common Core State Standards for math, incorporates STEM practices, and encourages students to develop 21st century skills (e.g., critical thinking, collaboration) inside and outside of the game. It is meant to be played over the course of a semester and revisited during each relevant curricular unit.

When players enter the game for the first time, they begin a sequence of tutorial quests designed to get players used to moving around the world, using tools, and collecting data about their environment. Upon completion of the tutorial quest line, an array of topical quest lines is unlocked. The game contains several quest lines including genetics, ecology, evolution, human body systems, geometry, algebra, and statistics. In this study, we will focus on the quest line of algebra. While the quests are sequenced within a topic area, players are free to switch between quest lines according to their interests throughout their play sessions. Each quest line may have anywhere from four to ten quests within it, and each quest is made up of multiple smaller tasks which provide some scaffolding to players. The quest content is aligned with curriculum standards, and the tasks are specific to the domain.

Figure 2 shows an example of the interface of Radix where the avatar of the player, called Tyrion, is situated in the middle of the screen. On the right side, we see the tools that the player has available; these are the tools that are used as part of the inquiry-based learning process to solve the quests. Moreover, on the bottom-right part of the interface, we observe the mini-map, that students use to travel through the world and reach the places needed to solve the different quests. On the bottom-left part of the interface we see the chat area, which is one of the main features enabling social interaction between the learners, with a general chat that anyone can write in and read, but also the possibility to send private messages to specific users in order to maintain communications that others cannot read. Moreover, students can also create groups to solve quests in a collaborative way. On the left side of the interface, we can see the inventory of the character, which contains the items that they can take from the Radix world, such as seeds, crystals, rocks, and plants among many other things. Finally, on the upper-left part of the interface, we see other available options in the menu panel such as the diary, the letters, the quest menu, and some other configuration tabs. Students need to interact with all these features in order to solve the quests.

[1] Radix trailer: https://www.youtube.com/watch?v=2fzphUwa6Lc

Figure 2. Example of the interface of Radix.

Pilot study

Radix was used across numerous schools in the US and also in other international countries. In this study, we focus on using the data from a controlled pilot study that ran from January 2014 through August 2015. While the game was designed with high school math and biology teachers in mind, Radix has been used by upper elementary, middle, and high school teachers as well as by a few instructors at community colleges and universities. During the pilot period, informal marketing and outreach was done to recruit teachers to participate in the pilot at various levels. Participating teachers were provided with professional development opportunities and implementation resources, which included in-person sessions, monthly webinars, an online forum, information on alignment with standards, and suggestions for bridging curriculum. Teachers were encouraged to tailor their implementations and use the game as they saw fit in their classroom; most had their students play relevant quest lines at the time they were covering a given topic area in their class. However, we did not have a tight control of the way teachers implemented Radix in their classes. Radix remained accessible to be played by anyone, and also to be used by teachers in their classes until late 2019. However, the game is not available any more on the web.

Several participating teachers implemented Radix in their classes. They were asked to align the quests selected for their students with the curriculum that they were teaching, and use both sets of contents (traditional and the ones provided by Radix) at the same time. From the several sets of contents that we explained previously, in this study we focus on algebra. Therefore, we use the data of those teachers that implemented Radix quest line on algebra while they were teaching algebra in their classes. Therefore, the pre- and post-tests that we utilize are also on algebra contents.

Pre-test, post-test, and enjoyment survey

The pre-test and post-test were the same identical test that focused on core algebra elements and was designed collaboratively with math teachers. The main difference is that the pre-test was taken by the students before interacting with Radix, and the post-test was taken by the students after finishing the sessions where they would be interacting with Radix. The procedure was designed so that we could guarantee a proper inference of the learning gains of students. In the case of the algebra test, there were 18 questions ranging across the different common core standards of algebra.

The enjoyment survey was taken after playing Radix game with the objective of measuring the levels of enjoyment that students experienced while playing the game. It had a total of 12 items that had to be responded in a 6-points Likert scale with the following categories: 'Completely False', 'Mostly False', 'Somewhat False', 'Somewhat True', 'Mostly True', 'Completely True'. Find below in Table 1 with each one of the items that were responded to as part of this survey.

Table 1. Items of the enjoyment survey.

Item	Statement
1	I would be willing to play "Radix" again because I think it is a fun game.
2	If I have trouble understanding a problem, I go over it again until I understand it.
3	When I run into a difficult homework problem, I keep working at it until I think I have solved it.
4	I would describe "Radix" as very interesting.
5	If I have trouble solving a problem, I am more likely to guess at the answer than to look at examples in the book to try to figure things out.
6	"Radix" let me do interesting things.
7	If I have trouble solving a problem, I will try to get someone else to help me.
8	I thought "Radix" was quite enjoyable.
9	I try to complete homework assignments as fast as possible without checking it.
10	When I run into a difficult homework problem, I usually give up and go on to the next problem.
11	When I read something for class that does not make sense, I skip it and hope that the teacher explains it in class.
12	I enjoyed participating in "Radix."

Metrics

In this subsection we describe the metrics that we computed. The in-game metrics were based on previous work that generated a multi-dimensional model of engagement in Radix based on four dimensions: The general activity, the exploration activity, social activity, and quest activity. Find below the specific definition of each one of the in-game metrics that we used:

- *active_time*: The number of active minutes in the game.
- *number_events*: The total number of actions (events in the logging system) generated by the student in Radix.
- *n_unique_zones*: Number of zones that the student visited in Radix.
- *n_different_explore_events*: There are 19 different tools or actions that a player can experiment with within the Radix world in order to solve quests and learn STEM content. This metrics provides a percentage of tools used by this student.
- *n_total_explore_events*: Number of events that are related to the use of experimental tools in the game.
- *p_completed_algebra_quests*: Percentage of completed questions by the student that belong to the algebra quest line.
- *p_correct_algebra_quests*: Percentage of correct attempts with respect to the total of the attempts performed within the algebra quest line.

- *p_change_quest_chain:* Since Radix does not force students to complete quest chains in a linear sequence, that means they can jump from one quest chain to another one, for example, from a biology quest to an algebra quest. This item measures how frequently the student changes from one quest to another. Therefore, if the value is very small, it means that the student tends to advance linearly in Radix, and if the number is high, it means that the student tends to jump from one quest line to another with high frequency.
- *n_chats*: Total number of chats sent by this student, taking into account both private messages between students to a single user and also zone chats that can be read by all users.
- *chars_per_chat_msg*: This metrics is calculated by dividing the number of total messages of a student by the number of alphanumeric characters of those messages, in order to provide an average value of the length of each chat message.
- *party_joined*: Total number of parties joined by the student. The parties in Radix allow students to group together in order to perform collaborative task solving.

In addition to the previous in-game metrics, we also use the following metrics obtained through the surveys:

- *pre_test*: Score obtained by the student in the pre-test taken before interacting with Radix, in order to understand the initial knowledge of the student.
- *learning_gain*: The learning gain of the student calculated by computing the difference between the post-test and the pre-test. Learning gains can range from -1 to 1.
- *avg_enjoyment*: This metric is an average measure of the 12 items from the enjoyment survey. Since there were six survey categories, we transformed them into an integer range from 0 to 6.

Final data collection

Since the in-game metrics are computed based on the tracking logs, and the rest of the metrics are computed based on the surveys, we had to link both sources of data together. This is done via the information provided in the survey by the student, which indicated the name of their character in Radix, and this allows us to properly merge both sources of data to perform this analysis. Moreover, for the final data collection, we had the following requisites to include a user account as part of the study:

- Teacher, staff, and research accounts were removed, leaving only accounts from students.
- We eliminated accounts that had not reached a minimum interaction of two hours, which is the estimation from designers for learners to getting familiar with Radix game mechanics.
- We kept only the accounts that had completed the first three quests of the tutorial, since the two first quests do not require any specific interaction with the environment– just speaking with the non-player characters (NPCs)–and the third task is the first one where they need to use a tool to correctly finish the quest.
- We kept only those accounts that completely responded to the pre-test, the post-test and the enjoyment surveys.

From the entire data sample, a cohort of 164 students met all the aforementioned criteria and are included in the study, 53% of the learners were male and 47% female. The majority of the learners were part of 6th and 7th grade classes (43% and 54% respectively), and the rest were in 8th grade. We would like to highlight that this is a good sample size considering all the instrumental work to organize the sessions and gather this data.

RESULTS

The results of this book chapter are organized into two subsections. The first one depicts an exploratory analysis of the different in-game metrics and survey ones to understand its distribution and results of the pilot study. The second one performs a correlational analysis to better understand the relationship between in-game activity, learning gains, and enjoyment.

Exploratory analysis of the metrics

The exploratory visualizations presented in this section will help to understand how the different metrics are distributed to better comprehend the interaction that students did with Radix as well as the survey results in terms of learning gains and the levels of enjoyment experienced by the students. In that sense, Figure 3 shows a boxplot visualization that includes all the previously defined metrics, which are grouped based on the category and filled with different colors. We have the in-game metrics, that are colored differently depending on their dimension (general activity, exploration, quests, and social) and we also have the survey metrics with a different color.

Regarding the activity metrics, the *active_time* is depicted in hours, therefore we see that the average user invested five hours playing with Radix, but there are multiple users as outliers that invested more than 20 hours, which is a significant amount of time. Moreover, we see a similar pattern with *number_events*, where the average user generated around 400 events but some users did more than 2000 events.

Regarding the metrics for the in-game exploration, the average user explored seven unique zones (*n_unique_zones*) of the Radix world, did six different exploration tool events (*n_different_explore_events*), and performed around 150 different exploration events (*n_total_explore_events*). These metrics depict how much each student explored the Radix world, without taking into account if they were able to advance with the algebra quest line (or with any other quest lines). We note that there might be some users that invested a lot of time or explored heavily the world of Radix, but did not progress with the quest system or performed badly in the survey post-tests.

Regarding the quest metrics, we first see based on *p_change_quest_chain* that the average user approximately tended to change between quest chains 20% of the times. This number is not so high, and therefore, most students tended to act in a more linear way. However, we do see some students with high numbers, above 40% and 50%, which would be students that perform frequent quest chain changes. We will see the impact that this can have in the next subsection. In terms of the two metrics on algebra quests, we see that the average user completed around 25% of the algebra quests, with the distribution clearly varying from 0 to 100% of algebra question completion (*p_completed_algebra_quests*). Therefore, there are important differences between how many quests the different students solved. Moreover, the percentage of correct responses in these quests (p*_correct_algebra_quests*) is around 70%, which is a high ratio that denotes that the difficulty was not too high, and most of the students that attempted to solve a quest, were able to complete it correctly.

In regards to the social metrics, we also see a great variability that denotes a key feature of Radix, which is the possibility for users to collaborate between them, generating a lot of social activity and interaction between peers. More exactly, we see that the average user sent around 80 chat messages (*n_chats*), which had around 10 chars per chat message (*chars_per_chat_msg*). These two indicators signal that the students did write many messages but also most of them were quite short messages. This of course changes importantly between users. In addition, the metric *party_joined* shows that the creation of parties to jointly solve quests was a common activity, as most users participated in at least three parties.

Finally, we have the survey metrics, where the *pre_test* indicates that the average user obtained a score of around 45 points from a maximum of 100. Therefore, we see that students started with an activity with a borderline knowledge on algebra. The pre-test score is widely distributed between this range, with users obtaining almost perfect scores and others failing almost all responses, as usual in K12 settings with a wide spectrum of kids. The results in terms of *learning_gain* are not very positive, since we see that the average learning gain was around 0 points, meaning that on average, the score in the pre-test and post-test was quite similar. It is also important to note that the distribution of the learning gains is also broad, so we have multiple cases of students that scored in the post-test much higher and lower than in the pre-test. There might be multiple reasons to explain this. At last, the *avg_enjoyment* metric shows a value close to 3 points over the maximum of 5 points. We believe this is a good number that denotes that the majority of students enjoyed the experienced of combining Radix algebra quests with the normal curriculum of algebra that their teacher was providing in their classes.

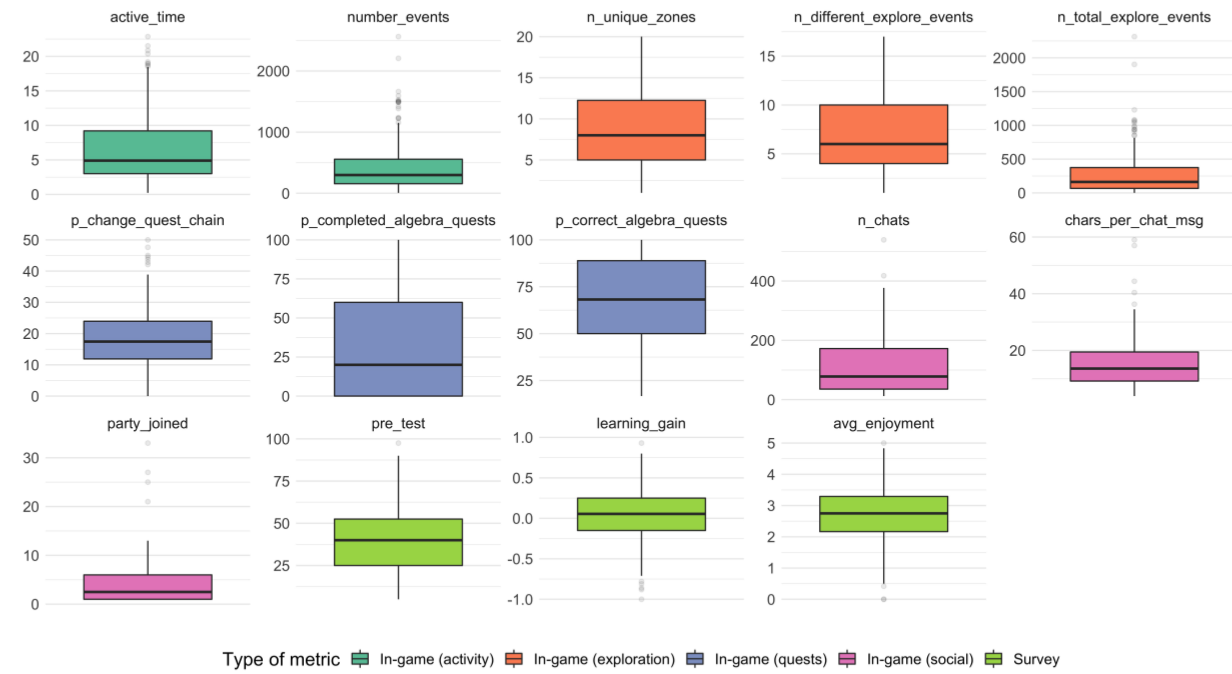

Figure 3. Boxplot visualization of the different in-game and survey metrics.

Correlations and interplay between the metrics

After presenting an overview of the metrics in the previous subsection, we now conduct a correlation analysis to see the interplay between the metrics. Figure 4 shows a correlation diagonal matrix that includes all the in-game and survey metrics considered in the study. The color intensity and the number on the cell encode the strength of the correlation with blue for positive ones and red for negative ones.

First, in terms of the correlations between the in-game metrics, we observe first the classical correlations between all the activity metrics, such as *number_events*, *n_unique_zones*, *n_different_explore_events*, and *n_total_explore* events, that are often present because all of them represent activity with the game. Moreover, these are also moderately correlated with the number of completed quests (*p_completed_algebra_quests*), however, the correlation is much lower with respect to the correctness ratio in those quests (*p_correct_algebra_quests*), which indicates that effort does not guarantee to resolve the algebra game quests correctly. One interesting highlight is the negative correlation between *p_change_quest_chain* and *p_correct_algebra_quests*, that indicates that those users that are less linear in their pathway, have lower chances to resolve the quests correctly. Finally, we see other noteworthy correlations between the social activity and other in-game metrics, for example, an important influence in the number of chars per chat message (*chars_per_chat_msg*) and the levels of activity and exploration.

We now focus on the correlations of the in-game metrics with the pre-test score and learning gains. First, in terms of the pre-test, we observe a positive correlation with the majority of the activity, exploration, and quest performance metrics, which can be connected to those students that had higher initial knowledge, enjoy algebra more, and therefore might enjoy the game more as well and solve more tasks. We do see also especially high correlations for the *party_joined* and *n_chats* social metrics, which might also be in relationship with a motivation with the game. Then, in terms of the learning gain, we observe a positive correlation with most of the activity and exploration metrics, which could mean that those students that interacted more with Radix, were able to improve their knowledge. Moreover, we also see a positive correlation with *p_correct_algebra_quests*, which indicates that the ones that achieved a better performance in Radix algebra tasks, also achieved a higher learning gain. Finally, we find a negative correlation with *n_chats*, indicating that students that texted less might have a higher learning gain.

Finally, one important correlation of 0.32 is the one emerging between the *learning_gain* of the student and *avg_enjoyment*, which indicates that those students that enjoyed the time spent playing Radix tended to learn more than their peers.

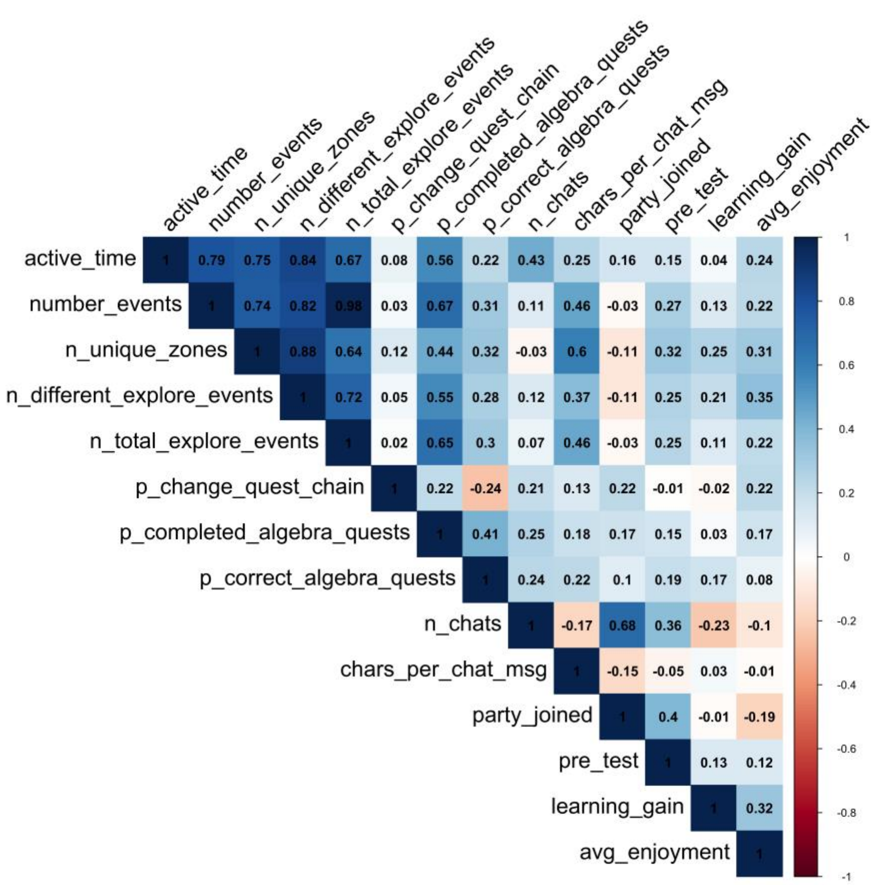

Figure 4. Correlation analysis of the in-game and survey metrics displayed in a diagonal grid. The color of the cell encodes the strength of the correlation.

DISCUSSION AND FUTURE RESEARCH DIRECTIONS

After presenting these results in this section we will provide potential explanations, discussion, as well as future research directions. First, in terms of the learning gains results, one of the first highlights was the low level of learning gains, with an average value close to 0. There are multiple interpretations that can come out of this. In the first instance, the teachers did not provide any encouragement to perform better in the external tests. Therefore, some students might have not taken them too seriously, and that might have affected the learning gains. Moreover, the algebra quest lines were designed to foster inquiry-based learning, and they were not directly connected with the contents of the administered external measures on algebra. If we compare these results with other studies implementing learning gains before and after interactive learning environments have reported much higher learning gains (Corbett, Kauffman, Maclaren, Wagner, & Jones, 2010; Kochmar et al., 2020), but these were more controlled cases studies, and the contents of the system were directly related with the test items. Moreover, we did find a correlation between most in-game activity metrics and learning gains, which raises a relationship between these two metrics. One explanation can be that students that interact more with the game learn more and thus improved their learning games. But another potential explanation can be just related to the motivation of students, and that might be the one driving them to improve as previous work saw with optional activities in MOOCs (J.A. Ruiperez-Valiente et al., 2016). Moreover, one interesting correlation was the negative one with the number of chat messages, which might be that those students that really took seriously the interaction with Radix did not focus on the social side that much. For example, a previous study did find a relationship between those profiles of students that socialize a lot within the game and learning outcomes, which might explain these results (J.A. Ruiperez-Valiente, Gaydos, Rosenheck, Kim, & Klopfer, 2020).

One positive outcome of these results was that the average enjoyment that students experienced with this game-based learning modality was high, with an average value close to three. This might be in line with what other studies have found regarding the students' perspectives with games and enjoyment (Yoon Jeon Kim & Shute, 2015). However, it is also true that some students might not enjoy games or gamification in general, since we also see that the distribution is wide. That means that it will be hard to find game-based approaches that can properly motivate entire K12 classes with very diverse learners, as previous work has found with gamification features in higher education (Ruipérez-Valiente, Muñoz-Merino, & Delgado Kloos, 2017). We also found that the level of enjoyment was directly correlated with in-game features, and it makes sense to think that those that enjoyed the experience had higher levels of activity with the game. One of the main take-aways is the relationship between learning gains and the level of enjoyment, which can connect that those students that enjoy the activities can learn more during the learning process. Therefore, this study highlights again the importance of motivating learners with the proper activities, and the other side of the coin, that learners that are not properly motivated will perform worse.

This book focuses on promoting economic and social development through serious games. Therefore, one of the most direct conclusions is that game-based learning approaches can suppose a significant improvement to increase the motivation of students, and that can help improve the overall learning that students achieve. Moreover, in Radix students were able to develop inquiry-based learning, exploring a virtual world and trying to understand algebra based on interacting with different features, learning by doing, without being passively exposed to the contents like is usually done in lectures. This has been depicted by several authors as one of the greatest assets of games for learning, which is the possibility to inhabit virtual worlds, in a way that resembles much more realistically the kind of challenges that they will face in real life (Gee, 2008; Prensky, 2006). In this work, we have depicted the potential of learning analytics in games to compute a set of in-game metrics that we were able to use to model the behavior of the students with the game. Therefore, these analytics also represent an important opportunity to perform game-based assessment, either for formative or summative purposes (Yoon Jeon Kim, Almond, & Shute, 2016). These assessments can be performed unobtrusively without impacting the game flow of students in what is known as stealth assessment (Shute, 2005), and then can be used to provide students with personalized feedback that can help them improve certain aspects. This can be done by developing teacher-facing dashboards in games that provide detailed information regarding the in-game activity of students with the game (Jose A. Ruiperez-Valiente et al., 2021).

More work will be needed in the future to validate these findings, either with other quest lines of Radix, or with other game-based learning experiences implemented in K12 classrooms. Future work should focus on addressing approaches to address those learners that might not be motivated by games, for example by better understanding the reasons so that these lessons learned can be looped back to the design of new serious games. Moreover, the learning analytics modeling in serious games also represents great opportunities, therefore future work should continue the development of these models, perhaps using more complex artificial intelligence techniques, or even developing new specific algorithms for the context of games. A clear challenge in this aspect is the scalability of these analytics across different serious games, an issue that needs to be tackled without a doubt if we want to systematically implement them (Alonso-Fernandez, Calvo, Freire, Martinez-Ortiz, & Fernandez-Manjon, 2017). Finally, another potential research opportunity within the context of serious games and learning analytics lies in the use of multimodal approaches using biometrics or audiovisual information, in order to augment the level of analysis and inferences that can be drawn (Blikstein & Worsley, 2016). All of these future directions can help serious games to make an extraordinary impact on society across diverse contexts.

CONCLUSION

This chapter has tackled a novel topic which was the interplay between in-game metrics, learning gains, and the levels of enjoyment. We have done so by presenting a novel methodology utilizing learning analytics to compute several behavioral indicators, and then we linked those to survey responses generated before and after playing with Radix game. Our main findings suggest a clear relationship between the learning games and the levels of enjoyment. However, while most of the learners enjoyed the experience, not all of them improved their knowledge. Both learning gains and enjoyment were in general positively correlated with in-game metrics, and those learners engaged much more with the platform than the rest. An issue that remains open regarding how to motivate those learners that did not find this game-based learning activity with Radix engaging, as this is something that has been frequently raised by other gamification and serious games case studies. This work has exemplified the potential that analytics approaches and serious games have to transform education and training across contexts.

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KEY TERMS AND DEFINITIONS

Educational technology: This term englobes technologies, software, and hardware that are used as part of the educational and training process of learners.

Game-based learning: This is the field that addresses how to use games as a medium to learn, either in informal or in formal contexts.

In-game metrics: When players interact with the game, they generate tracking logs which are raw data containing a detailed record of the actions that they performed during the game. This term refers to using quantitative approaches to transform the raw data in metrics that can reconstruct the behavior of players with the game.

Learning analytics: This field of research collects data from the learners and the educational context where the education is taking place and applies quantitative and qualitative methods to understand and improve the learning process and the context where it is happening.

Learning gains: This metric is computed by calculating the difference between a post-test and a pre-test. The pre-test usually takes places before developing a learning activity and the post-test after the activity is finished. It helps understand if students are learning or not.

Serious games: These are games that have as main purpose one beyond entertainment, for example learning, training a user to change their habits, or health rehabilitation.

STEM education: This term refers broadly to education on science, technology, engineering, and math topics, which is often considered as a specific branch of education to the specific nature and pedagogical approaches of these knowledge areas

Technology-enhanced learning: This term refers specifically to improve learning with the use of technology, and therefore it needs to justify how the technology has improved the previous learning setup.