Student Agency and Game-Based Learning: A Study Comparing Low and High Agency

Huy Nguyen[1], Erik Harpstead[2], Yeyu Wang[2], and Bruce M. McLaren[2]

[1] Lafayette College
[2] Carnegie Mellon University

Abstract. A key feature of most computer-based games is agency: the capability for students to make their own decisions in how they play. On one hand. agency is assumed to lead to engagement and fun. On the other hand, agency may or may not be helpful for learning. While the best learners are often good self-regulated learners, many students are not, benefiting from instructional choices being made for them. In the study presented in this paper, involving a total of 159 fifth and sixth grade students, children played a mathematics learning game called *Decimal Point*, which helps middle-school students learn decimals. One group of students (80) played and learned with a *low-agency* version of the game, in which they were guided to play in a prescribed sequence, playing all "mini-games" within the larger game. The other group of students (79) played and learned with a *high-agency* version of the game, in which they could choose how many and in what order they would play the mini-games. The results show that all students learned from the game, but there were no significant differences in learning or enjoyment across the low and high-agency conditions. A key reason for this may be that students across conditions did not substantially vary in the way they played the game, perhaps due to the indirect control features present in the game. It may also be the case that the young students who participated in this study did not exercise their agency or self-regulated learning. This work is relevant to the AIED community, as it explores how game-based learning can be adapted. In general, once we know which game and learning features lead to the best learning outcomes, as well as the circumstances that maximize those outcomes, we can better design AI-powered, adaptive games for learning.

1 Introduction

There is palpable interest in the potential of educational games to engage students and enhance learning. Teachers are particularly excited about the use of educational games in their classrooms, with a high percentage having their students use games for learning at least once a week (55% of 513, according to [8]). At the same time, young people are playing computer games at an ever increasing rate. For instance, [14], reported a playing frequency of 4.9 to 5.8 hours per week for children age 7 to 12. The enthusiasm for educational games, combined with

the increasing interest of young people in playing computer games, is leading to a revolution in education, with educational games in the forefront.

At the same time, scientific research has started to provide evidence that games can be effective for learning [2, 4, 13, 18, 31]. For instance, research has shown the benefits of learning decimal mathematics with an educational game called *Decimal Point*, which was designed based on theory and evidence about common student misconceptions [7]. In a study involving more than 150 middle school students, *Decimal Point* led to significantly more learning and was self-reported by students as significantly more enjoyable than a more conventional computer-based tutoring approach [20]. Other studies, in the areas of mathematics [10, 21], science [1, 11], and language learning [28, 32], have shown similar learning and/or engagement benefits for educational games.

The search is now on for the specific features of games that lead to engagement and learning benefits, as well as how we can best leverage those features to maximize the potential of educational games [2]. Potential game features to explore include game challenge, fantasy, in-game actions, in-game objects, animation, game environment, and feedback [6,17]. For instance, Lomas and colleagues have explored the benefits of increasing challenge in an educational game, finding that increasing challenge doesn't necessarily increase motivation and learning; students were generally more motivated by "easy" versions of games [15,16]. Another key feature of educational games is the degree to which *agency* is provided, the capability for students to decide how to play games - what they will explore, how long they will play, and when they will try out various game features. Agency is often viewed as a component of engagement [22], which in turn leads to fun. Yet, agency, which is closely related to self-regulated learning [34], may or may not be helpful for learning. While the best learners, those who demonstrate achievement on tests, are often good self-regulated learners [25,34], many students are not good at regulating their learning, benefiting from instructional choices being made for them through direct instruction [33].

Several past studies have explored the effects of agency, giving students control over the way they play an educational game. For example, [29] showed that allowing students control over the time in which they engage with different lessons in multimedia learning can lead to higher learning outcomes. Approaching agency from a different perspective, [3] allowed the customization of game icons and names in their fantasy-based arithmetic tutor, while [26] provided in-game currency, which could be spent on either personalizing the system interface or extra play. In these studies, student agency was restricted to instructionally irrelevant components of the learning experience, so that students could achieve a sense of control without the risk of their making pedagogically poor decisions. The results demonstrated that students did become more involved, used more complex operations and thus learned more.

A notable example of studying student agency, in which students were given instructionally relevant choices, comes from Sawyer et al [23] who explored variations in agency within the game *Crystal Island*. In *Crystal Island*, students are tasked with exploring an island and interacting with people and objects to gather knowledge about a spreading disease. The students also learn microbiology along

the way. There were three agency conditions in this study: high-agency, which allowed students to navigate to locations in the environment in any order; low-agency, which restricted students to a prescribed order, and no-agency, where students simply watched a video of an expert playing the game. In their study Sawyer and colleagues found that students in the low-agency condition attempt more incorrect submissions but show significantly higher learning gains, which might be attributed to their extensively engaging with instructional materials. Their results suggest that limiting agency improves learning performance but can also lead to undesirable student behaviors, such as a propensity for guessing.

In our study presented we explore variations of agency within *Decimal Point*, the educational game briefly described above. Our study compares a low-agency version of the game, in which students are guided to play in a prescribed sequence, playing all possible "mini-games", to a high-agency version of the game, in which students can choose how many and in what order they will play the mini-games. The study is comparable to Sawyer et al [23] in its exploration of agency; students are compelled either to play the game in a lock-step order or to have autonomy to make their own choices about game play. In addition, the choices students are presented with in both *Decimal Point* and *Crystal Island* are pedagogically relevant. In the high-agency version of *Decimal Point*, a student can choose to play mini-games that focus on specific aspects of the content domain (e.g., adding decimals, comparing decimals, completing decimal sequences), as well as choosing to get more or less practice with decimals (and game playing). Our research questions and hypotheses for the study are as follows.

Research Question 1. *Is there a difference in learning performance between students who play the low-agency version of the game versus the students who play the high-agency version of the game?* Given the results of the Sawyer et al study [23], as well as the similarities between our implementation of agency and theirs, we hypothesized that the low-agency version of the game would lead to better learning outcomes than the high-agency version of the game.

Research Question 2. *Is there a difference in enjoyment between students who play the low-agency version of the game versus the students who play the high-agency version of the game?* Given past research on agency in which it has been shown that students prefer to make their own choices, regardless of whether those choices are pedagogically beneficial [3, 23], we hypothesized that the high-agency version of the game would lead to higher levels of enjoyment than the low-agency version of the game.

2 The Educational Game: *Decimal Point*

Decimal Point is a single-player game designed to help middle-school students learn decimals. The game is based on an amusement park metaphor (Figure 1), with the student traveling to different theme areas (e.g., Wild West, Space Adventure), playing a variety of mini-games within each area (e.g., "Western Shooter", and "OK Corral,"within the Wild West theme area). The mini-games within each theme area are targeted at helping students overcome common decimal misconceptions [9, 12, 27]. Students do not score points or compete with

their fellow students. Instead, they simply play the mini-games in the amusement park and are commended upon completing the journey. There are no other activities within *Decimal Point* beyond playing of the mini-games.
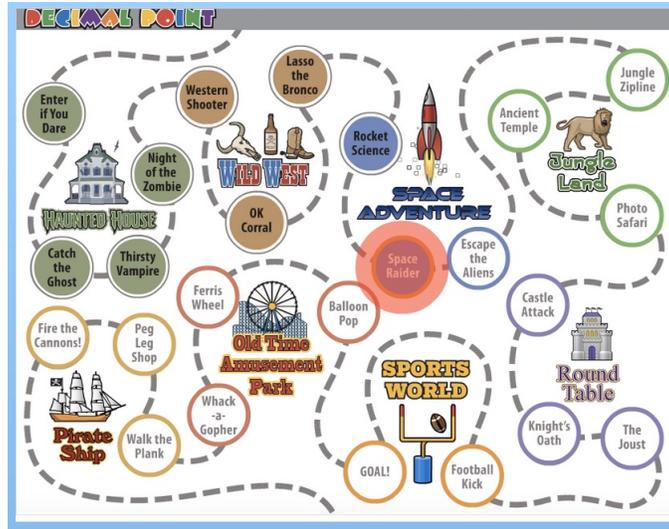

Fig. 1. The *Decimal Point* game (low-agency version).

An example mini-game, "Space Raider," is shown in Figure 2. This game challenges the student to use laser guns (lower left and right of Figure 2) to shoot decimal-labeled spaceships (e.g., `0.3234, 0.5, 0.82, 0.634`) in the order from smallest to largest decimal. The "Space Raider" mini-game is targeted at "whole number thinking," a common misconception in which students think longer decimals are larger than shorter decimals [27]. The student tries to shoot the spaceships in the requested order and, if they make mistakes, are prompted to correct their solution by dragging and dropping the numbers into the correct sequence. Feedback in this mini-game is provided at the end of the game, once students have shot all the spaceships. In Figure 2, the student has exhibited the misconception by shooting the spaceships in length order: `0.5, 0.82, 0.634`.

In the original version of *Decimal Point*, students are prompted to play each mini-game in a pre-specified sequence, according to the dashed path shown in Figure 1, starting from the upper left. In the study discussed in this paper, this is referred to as the low-agency version of the game, since student choice is limited. In order to explore agency, we extended the game to a high-agency version that allows students more control over their experience and learning. In the high-agency version of the game, depicted in Figure 3, students are given several choices. First, they can play the mini-games in any order they choose. Students are presented with a dashboard that displays the five different categories of mini-games (i.e., (1) "Addition - Add decimals", (2) "Bucket - Compare decimals", (3) "Sequence - Complete a decimal sequence", (4) "Number Line - Place point on number line", (5) "Sorting - Ordering decimals"), as well as the specific mini-
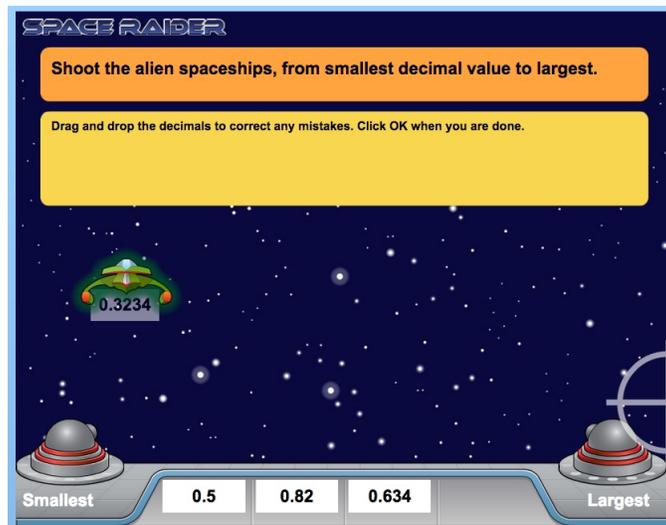
Fig. 2. A student playing the "Space Raider" mini-game

games within each category. In Figure 3 three mini-games have been played - Enter if you Dare, OK Corral, and Ferris Wheel - indicated by those mini-games being colored in the map and the names of the mini-games shown in red font in the dashboard. By mousing over the various games, the student can learn about each game (e.g., Mousing over Night of the Zombie displays "Freeze a zombie with a powerful amulet - Correctly place a decimal number on a number line") giving them information to make informed choices.

Second, students can stop playing *Decimal Point* once they have finished playing at least one-half of the mini-games, as shown in Figure 4. When they reach the halfway point, they are presented with a dialogue that says "You have finished playing half of the mini-games. You can keep playing until all games have been played or stop at any time by clicking on the Stop Playing button," and a new "Stop Playing" button appears in the upper left, as in Figure 4. At any time from this point until they finish playing all of the games, students can click on "Stop Playing" to quit playing and proceed to the next item in the materials.

Finally, once students have completed every mini-game once (2 problems per mini-game), they can play more mini-games, any of the original 24 games, for one additional problem each. They are also presented with a dialogue telling them they can keep playing (i.e., "You have played all of the mini-games. You can now either quit (by clicking on Stop Playing) or replay some of the mini-games") and a "Stop Playing" button that allows them to stop playing at any time (Figure 4). These changes means altogether that students playing the high-agency version of *Decimal Point* can play from 24 up to 72 mini-games (compared to the standard 48 in the low-agency condition), in any order of their choosing.

As mentioned, the original (low-agency) version of the game has been empirically demonstrated to be effective for engagement and learning. In our previous study [20], students were assigned to one of two conditions that were compared:
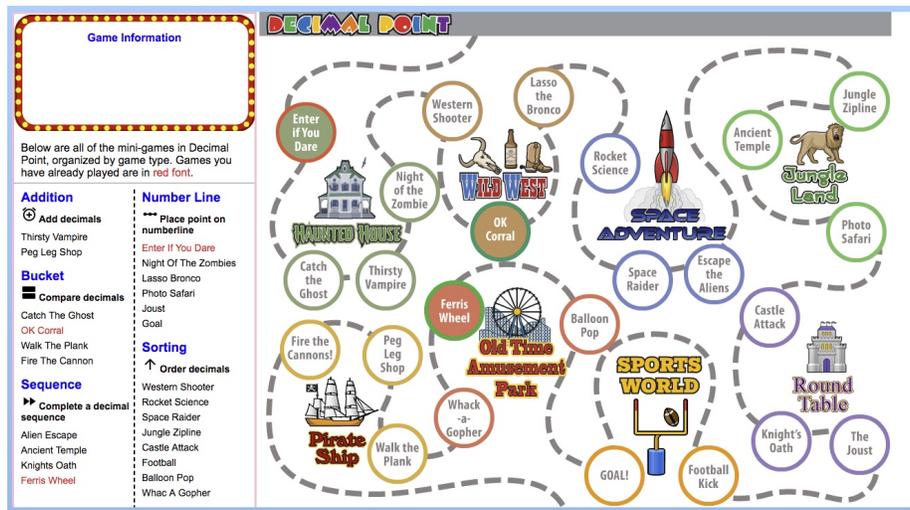
Fig. 3. High-agency version of the *Decimal Point game*

the game condition and the non-game condition. Students in the game condition were presented with two problems to solve for each of the mini-games shown in Figure 1. The non-game condition presented a more conventional user interface to the students, prompting students to solve precisely the same decimal problems, in the same order. [20] compared 75 game-playing students to 83 non-game-playing students and found that the game-playing students enjoyed their experience more and learned more. In subsequent data analyses, we also found that female students benefited more from *Decimal Point* than male students, and the game made difficult problems more tractable for all students, as students in the game condition made significantly fewer errors on the difficult problems than students in the non-game condition [19]. In this paper, we describe a study to explore how extending the agency feature of the game might alter student learning.

3 Method

3.1 Participants and Design

The original participants were 197 students from two schools in a large U.S. city (45 fifth and 152 sixth graders). Students were randomly assigned to either the high-agency (HA) or the low-agency (LA) condition. Thirty-two (32) participants (19 HA, 13 LA) were excluded from the analyses because they did not fully complete all materials and measures in the study. An additional six (6) participants were removed due to having gain scores 2.5 standard deviations above or below the mean between the pretest and the immediate posttest or between the pretest and the delayed posttest. The remaining 159 students (82 male, 77 female) had a mean age of 11.14 (SD = 0.604).

Fig. 4. High-agency version of the *Decimal Point* game after the student has played one-half of the mini-games and is given the option to stop. A "Stop Playing" button appears on the dashboard in the upper left.

3.2 Materials

A web-based learning environment was used to deploy the experiment, and the instructional materials were assigned to each group as outlined in Table 1. Materials included three tests (pretest, posttest, delayed posttest), the game or non-game materials, and two questionnaires (demographic, evaluation). Details about the materials are provided in the remainder of this section.

Pretest, Immediate Posttest, and Delayed Posttest. The pretest, immediate posttest, and delayed posttest (which was administered one week after the posttest), were administered online. Each test consisted of 24 items, some of which had multiple parts, comprising 61 possible points. Participants received points for each correct part. There was an A, B, and C form of the base test, which were isomorphic to one another and which were positionally counterbalanced within condition (i.e., approximately 1/3 of the students in each condition received Test A as the pretest, 1/3 received Test B as the pretest, and 1/3 received Test C as the pretest; likewise for the posttest and delayed posttest).

Test items were designed to probe for specific decimal misconceptions and took a variety of forms, for instance: adding, multiplying, and dividing decimal numbers (e.g., `0.387 + 0.05 = ____`), choosing the largest of a given set of decimals (e.g., "Choose the largest of the following three numbers: `5.413, 5.75, 5.6`"), and placing a given decimal number on a number line.

Questionnaire. After finishing the lesson, an online questionnaire was presented to the students, prompting them to rate their experience of interacting with the instructional materials. Students could respond on a 5-point Likert scale, ranging from 1 = "strongly disagree" to 5 = "strongly agree". For the purpose of our

Table 1. Conditions and Materials used in the study. *Italicized* items vary across conditions.

High-Agency Game	Low-Agency Game
Pretest (A, B or C)	Pretest (A, B or C)
Demographic Questionnaire	Demographic Questionnaire
Game Play *(between 24 and 72 mini-game items played, in order of student choice.)*	Game Play *(Exactly 48 mini-game items played, in prescribed order.)*
Evaluation Questionnaire	Evaluation Questionnaire
Immediate Posttest (A, B or C)	Immediate Posttest (A, B or C)
Delayed Posttest (A, B or C)	Delayed Posttest (A, B or C)

analysis, the eight items in the questionnaire were combined into the following three different categories:

1. *Lesson Enjoyment* indicates the how well students like the lesson. Items included: "I liked doing this lesson" and "I would like to do more lessons like this."
2. *Ease of Interface Use* indicates how easy to interact with the intervention items and interface for the lesson. Items included: "I liked the way the material was presented on the screen", "I liked the way the computer responded to my input ", "I think the interface of the system was confusing. ", and "It was easy to enter my answer into the system."
3. *Feelings of Math Efficacy* indicates how students feel about math after completing the intervention. Items included: "The lesson made me feel more like I am good at math" and "The lesson made me feel that math is fun. "

4 Results

Here we present results according to our two research questions, followed by subsequent post-hoc analyses we conducted.

Research Question 1. *Is there a difference in learning performance between students who play the low-agency version of the game versus the students who play the high-agency version of the game?* With pretest scores used as a covariate, we ran an ANCOVA to assess gain scores for both pretest-immediate posttest and pretest-delayed posttest. Results are shown in Table 2. The LA group performed slightly better than the HA group on the immediate posttest ($F(2,156) = 43.79, p = 0.231, d = 0.14$) but worse on the delayed posttest ($F(2,156) = 26.308, p = 0.120, d = -0.23$). No results are significant.

Interestingly, when broken down by separate schools – one in which we experimented with sixth graders (School 1) and a second in which we experimented with fifth graders (School 2) – we see a significant result. Again, applying ANCOVA with pretest scores as covariates, in School 1 (6th graders) the low-agency group ($n = 61$) performed significantly better than the high-agency group ($n = 61$) on the immediate posttest ($F(2, 119) = 39.45, p = 0.035, d = 0.52$). However, the low-agency group performed slightly worse, but not significantly so, on the delayed posttest ($F(2, 119) = 20.14, p = 0.259, d = 0.16$).

Table 2. Learning results across conditions.

	Low Agency ($n = 80$)	High Agency ($n = 79$)	Effect Size (d)
Pretest (max = 61)	36.18 (12.6)	35.90 (12.2)	0.02
Posttest (max = 61)	42.03 (9.5)	40.85 (10.5)	0.11
Delayed Posttest (max = 61)	41.97 (10.6)	43.06 (11.0)	-0.10
Pretest-immediate posttest scores	5.85 (6.6)	4.95 (6.3)	0.14
Pretest-delayed posttest scores	5.76 (6.2)	7.16 (6.1)	-0.23

For School 2 (5th graders) the low-agency group ($n = 19$) performed slightly better, but not significantly, than the high-agency group ($n = 18$) on the immediate posttest ($F(2, 34) = 7.875, p = 0.341, d = -0.38$). However, the low-agency group performed slightly worse, but not significantly so, on the delayed posttest ($F(2, 34) = 6.04, p = 0.198, d = -0.47$).

In summary, our hypothesis that the LA group would learn more than the HA group was not confirmed, except with respect to one of the schools, and only on the immediate posttest.

Research Question 2. *Is there a difference in enjoyment between students who play the low-agency version of the game versus the students who play the high-agency version of the game?* Three categories that roughly summarize how students enjoyed and felt about the game (i.e.. Enjoyment in the Lesson, Ease of Interface Using, Self-evaluation of math efficacy) were assessed by one-way ANOVA. For lesson enjoyment, the high-agency and low-agency groups do not significantly differ ($F(1, 157) = 0.002, p = 0.969, d = -0.006$). For Ease of Interface, again, the two groups do not significantly differ ($F(1, 157) = 0.05, p = 0.823, d = -0.036$). Also, for Feeling of Math Efficacy the groups do not significantly differ ($F(1, 157) = 0.718, p = 0.398, d = 0.134$).

In summary, our hypothesis was not confirmed that the HA group would experience a higher level of enjoyment with the game than the LA group.

Posthoc Analyses. Given the results and answers to our research questions, we performed post-hoc analyses to better understand why we did not see the differences we expected between the high-agency and low-agency game conditions.

Table 3. Engagement results across conditions.

	Low Agency ($n = 80$)	High Agency ($n = 79$)	Effect Size (d)
Lesson enjoyment (1-5)	4.0 (1.0)	4.0 (0.9)	-0.01
Ease of interface (1-5)	3.9 (0.7)	3.9 (0.6)	-0.04
Math efficacy (1-5)	4.0 (1.0)	3.9 (1.0)	0.13

In particular, we were interested in exploring what the high-agency students did with the additional control they were given in game play. Did they take advantage of it, to explore the game and have more fun? Did they leverage the autonomy to make self-regulated learning choices?

To further explore these questions, we looked at the specific mini-games and mini-game sequences that were chosen by players in the HA condition. The number of high-agency students who did less than, exactly the same, and more than the canonical number of problems are 15, 54, and 10, respectively (School 1: 11, 42 and 8; School 2: 4, 12 and 2). Thus, a significant majority – 68% – played the same mini-games as that provided in the LA condition. Furthermore, we found that 22% of students in the HA condition precisely followed the canonical sequence (i.e., the sequence prescribed in the LA condition, as shown in Figure 1). To get a sense of how different the level sequences of students in the HA condition were from the canonical sequence we calculated Damerau-Levenshtein distance between each students' sequence and the canonical one. Damerau-Levenshtein distance counts the number of insertions, deletions, substitutions, and transpositions needed to turn one string into another [5]. In addition to raw Damerau-Levenshtein distance we also calculated a length matched distance, which measured either the edit distance between a student's sequence and a subsequence of the canonical sequence in the event the student played less than 24 levels or a subset of the student's sequence of equal length to the canonical sequence in the event they played more levels. This modified edit distance avoids inflating the distance for those students who chose to play more or less while still giving a qualitative sense of how similar their path was to the standard path.

In general, the distributions of edit distances are lopsided, due to so many players followed the prescribed order. On average players' sequences differed by about 13.07 edits (SD = 9.73) from the standard order, meaning roughly half of the mini-games they played followed the expected sequence. When controlling for sequence length (i.e., when students chose to play more or less mini-games) this effect is further tempered to 10.77 edits (SD 8.83) from the standard order.

In addition to the distributional information we also checked to see if a student's edit distance from the canonical sequence had any effect on their pretest-posttest or pretest-delaytest learning gains. Using a repeated-measures ANCOVA no significant effects were found for pretest-posttest $F(1, 78) = 0.18, p = 0.67$ or pretest-delayed posttest $F(1, 78) = 0.00, p = 1.00$. This would mean that

the amount of difference between a student's chosen ordering and the prescribed ordering has little effect on their learning gains.

5 Discussion

We hypothesized that our findings would be roughly a replication of the findings in [23], given the similarities in implementation of agency here is similar to theirs. However, other than the finding at School 1, in which the low-agency students did exhibit a better learning outcome than the high-agency students, we did not replicate their findings. Instead, we found no overall differences in learning between the low- and high-agency students who played *Decimal Point*. Given that our results only partially replicate those of Sawyer and colleagues we are left with the question of explaining why this happened.

As stated earlier, our implementation of agency has key aspects in common with [23]. For instance, students are compelled either to play the game in a specific order (low-agency condition) or to have autonomy to make choices about the order of game play (high-agency condition). In addition, the choices students are presented with in both games are pedagogical relevant, unlike other studies of agency, such as [3,26], in which the choices were unrelated to learning elements in the games. However, there are also differences between the agency provided in *Decimal Point* and in *Crystal Island*. One difference is that, unlike the high-agency version of *Crystal Island*, the *Decimal Point* high-agency game tracks student progress (through the provided dashboard - See Figures 3 and 4) showing the types of mini-games and problems that are available, allowing students to make informed choices about their next course of action. Perhaps more importantly, in *Decimal Point* the high-agency students are given the choice to stop or continue playing, a game feature that is not part of the high-agency version of *Crystal Island*. More specifically, the *Decimal Point* high-agency students had the option to stop playing after finishing 24 problems (12 mini-games, one-half the overall number) or at any time after that. The *Decimal Point* high-agency version of the game also allowed students to tackle more problems by playing additional games once they had finished the standard 48 problems / 24 mini-games. This means that *Decimal Point* high-agency students were able to gain more (or less) practice on the relevant domain problems.

Interestingly, however, it appears that the high-agency *Decimal Point* students did not exercise their given agency very much. As mentioned above, 68% of the high-agency students tackled precisely the same problems as the low-agency students. Additionally, the sequences of mini-games chosen by the students did not substantially vary from that of the low-agency condition. One possible explanation for why the high-agency students did not diverge much from the canonical path could be related to the design of *Decimal Point*'s map and select screen (see Figures 3 and 4). While the high-agency select screen was modified to allow students to choose their next mini-game, the presentation of the amusement park map was largely unchanged, including the dotted line connecting the different mini-games. It is possible that this dotted line implicitly (and unintentionally) communicated a standard sequence of mini-games to follow. Thus, this could be

an unintended case of "indirect control" [24], where subtle pieces of visual design can be used to draw students' attention and guide behavior without explicit direction. There has been little empirical study of this phenomenon, which suggests interesting future work exploring high-agency conditions with and without this implicit guidance to see whether students' variation in choice increases.

Another possible interpretation points to nuances in the nature of agency within games. [30] provide one of the more comprehensive discussions of agency within games. In their definition, agency is described as a balance between a player's desires and the possible actions supported by the game. Under this interpretation of agency it would be possible to increase the number of supported actions in a game without seeing much difference in play if players have no desire to play differently. Put another way, it is possible that students in our sample simply had little interested in making choices about what mini-games to play next, or how many mini-games to play, and so increasing their agency to do so would not make a difference as a manipulation. Exploring this question would require more detailed insight into the reasons behind why students chose to play the mini-games they did. We did provide a survey after students used the materials asking which mini-games they preferred, so that would be a start at investigating this topic, which we will explore in future work.

Finally, the results from a learning versus a game playing persepctive suggests that students simply did not exercise good self-regulation in their learning. The dashboard provided in the high-agency condition was intended to give students not only a view of the mini-games they could play and had played, but also the pedagogical content of those game. As shown in Figure 3, and described earlier, both mini-game mouse overs and the dashboard provide information about the learning goals of each game (e.g., Mousing over Night of the Zombie displays "Freeze a zombie with a powerful amulet - Correctly place a decimal number on a number line"). Yet, we know that students are often not good self-regulated learners [34]; younger students are likely to be even weaker in SRL.

6 Conclusion

This study of student agency was intended to explore the earlier results of [23], investigating whether providing students agency in a game context would increase or decrease their learning. In this study, we did not find that students in a low-agency condition learned more than the students in a high-agency condition (except for one school). As is often the case, shifting the context of instruction can change the results. In our case, it may be that our materials provided more indirect control of student behavior than intended, thus washing out the differences between low- and high-agency versions of the game, or perhaps younger students simply don't exercise agency or are not good self-regulated learners. In any case, educational game studies such as this are important in helping us better understand and make decisions about how to implement adaptivity in games, which ultimately artificial intelligence will control. Once we have a better understanding of the specific context in which, for instance, agency leads to better learning, we can develop AIED-infused games that adapt to those contexts.

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