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Chapter 3

Digital Games in the Science Classroom: Leveraging Internal and External Scaffolds during Game Play

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Abstract

We have developed a disciplinarily integrated game (DIG) to support students in interpreting, translating, and manipulating across formal representations in the domain of Newtonian kinematics. In this study, we seek to understand what game play looks like in a classroom context with particular attention given to how students leverage internal and external scaffolds to progress through the game and deepen their conceptual knowledge. We investigate the following questions: (1) In what ways do students interact with the game, with each other, and with their teacher when they play *SURGE Symbolic* in a classroom environment? (2) How do game scaffolds, both within and outside of the game, support or impede student learning and game play? (3) What are the implications of these observations for teachers and game designers? We found that although most students used internal scaffolds in some way to assist their game play, many found that these scaffolds were insufficient to get through challenges. They quickly sought help from external resources available to them outside the game to help them advance in the game. The source of information they needed to make progress came from various people or resources outside the game, what we are calling "knowers."

Keywords: game-based learning, disciplinarily integrated games, science education, game design, scaffolds

1. Introduction

Interpreting, translating, and manipulating across formal representations is central to scientific practice and modeling [1–3]. We have developed a disciplinarily integrated game (DIG) such that players' actions in the game focus on iteratively developing and manipulating formal representations as the core game mechanics [4, 5]. These formal representations are computational and mathematized representations of focal science phenomena. Through playing a DIG, students investigate key conceptual relationships in the domain while also developing facility with the representations and inscriptions themselves [6]. Supporting students in manipulating and transforming across representations, however, is challenging in terms of having students build connections between the formal representations and patterns of events that they represent [7–10]. This study extends work from our previous pilot study [11] and used a DIG in the context of Newtonian kinematics. This DIG is designed to engage students in the manipulation of both formal representations and events (in this case, patterns of motion) to control one another in order to develop a deeper conceptual understanding of physics concepts. In this study, we seek to understand what game play looks like in a classroom context with particular attention given to how students leverage internal and external scaffolds to progress through the game and deepen their conceptual knowledge.

2. Background

2.1. Internal and external scaffolds

The notion of scaffolding was originally conceived as a process by which teachers, other adults, or peers provide assistance to help learners with tasks that are normally beyond their reach [12]. Scaffolds can be directly embedded into an activity in order to provide learners with "just in time" resources that help students overcome a challenge at the moment they encounter the challenge. In games for learning, these internal scaffolds can take the form of hints, questions, terminology, character dialogs, feedback screens, etc. Researchers have found that internal scaffolds can support students in developing science content and skills [13]. It is important that internal scaffolds go beyond helping students simply progress to the next level in the game but also engage them in learning from their efforts on a level so that they can then apply that newfound knowledge to the subsequent game levels [14]. In the context of this paper, internal scaffolds are supports that are embedded within the game that are designed to foster students' conceptual understanding of Newtonian kinematics and intended to help students make connections between the informal context of the game and the formal physics vocabulary and representations used to describe motion of objects. These scaffolds include help screens and hints when a student fails to solve a level, as well as tutorials that provide new information (e.g., explanations of formal physics representations like graphs and dot traces) for future levels.

In addition to internal scaffolds embedded within the game environment, external scaffolds can also be used to enhance students' learning [15]. In the context of games, external scaffolds may come from a teacher or peers in the form of scientific explanations of concepts in the game or advice on when to perform certain actions in a game. Additionally, providing collaboration opportunities between peers during game play can serve as a productive external scaffold that allows students to leverage discourse in order to negotiate meaning of concepts and actions within games, construct ideas, resolve conflicts, etc. [16, 17]. In the context of the current study, although most students used internal scaffolds in some way to assist their game play, many also found that these scaffolds were not enough to get through challenges. They quickly sought help from external resources available to them *outside* the game to help them advance *in* the game. The source of information they needed to make progress came from various people or resources outside the game, what we are calling “knowers.” Students chose to seek help from the teacher, each other, and even other tools and materials to reason through the math and science needed to pass a level.

Despite the well-known affordances of digital games for students’ conceptual development, these games have not been widely adopted in secondary science classrooms [15]. A primary goal of this project was to explore what real game play with DIGs looks like in the classroom context to improve our understanding of how students engage with the game and the science concepts embedded within the game. In addition to exploring the impact of the new world-view levels, we were also particularly interested in exploring how students overcome challenges in the game when they have access to a classroom of peers and a teacher. Honey and Hilton [15] call for research to “investigate how best to integrate games into formal learning contexts…this should include how *internal scaffolds* in the game and *external scaffolds* provided by a teacher, mentor, peers, or other instructional resources support science learning” (p. 124). It was of interest to us to explore when, who, and how students solicit support to succeed with their personal game play goals. This exploratory study addresses this research need by investigating the following questions: (1) In what ways do students interact with the game, with each other, and with their teacher when they play *SURGE Symbolic* in a classroom environment? (2) How do game scaffolds, both within and outside of the game, support or impede student learning and game play? (3) What are the implications of these observations for teachers and game designers?

2.2. Disciplinarily integrated games

SURGE Symbolic (**Figures 1** and **2**) is the prototypical DIG template that we used in this study, and is the result of evolution of design, research, and thinking chronicled in Clark et al. [4, 5]. Whereas earlier versions of *SURGE* supported reflection on the results of game play through formal representations as a means to support strategy refinement, the formal representations were not the medium through which players planned, implemented, and manipulated their game strategies. Earlier versions of *SURGE* provided vector representations, for example, to help students understand what was happening and how they might adjust their control strategy, but these formal representations only communicated information that a player might or might not use. The challenges and opportunities in a given game level, however, were communicated through the layout of elements in the game world, not in the formal representations. Similarly, the player’s controls for executing a strategy were also independent of the formal representations. Thus, while attending to the formal representations might help a player succeed in a level, earlier *SURGE* games did not use formal representations as the medium through which challenges and opportunities were communicated to the player, nor did earlier *SURGE* games use diagrammatic formal representations as the medium of control. In *SURGE Symbolic*, we made Cartesian graphs of position and velocity over time the medium through which the player controlled their avatar in the game, and we also made those same types of Cartesian graphs the medium through which the game communicated goals and challenges to the players.

Figure 1. Anatomy of an introductory block level.

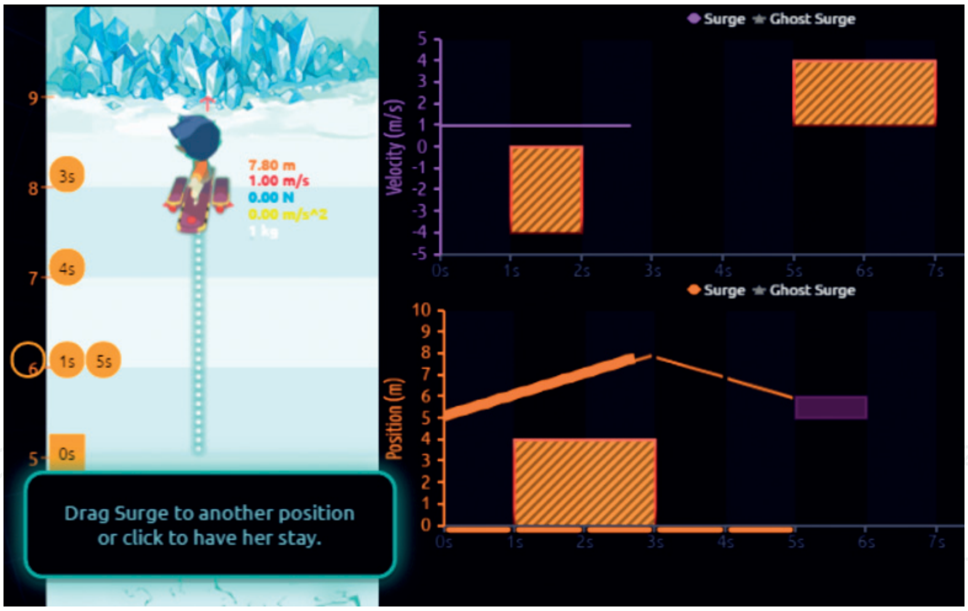

Figure 2. Anatomy of an introductory worldview level.

Students in *SURGE Symbolic* play from the perspective of the space navigator, Surge. Game play is divided into levels, each focused on a specific navigational challenge or Newtonian concept. Students must move Surge forward or backward on her space board to find the appropriate position or velocity to navigate Surge to the exit portals, represented by a purple box, while avoiding electricity zones, represented as orange boxes (see **Figure 1**). Surge's path is traced onto a graph representing the magnitude of position and velocity over time. Students

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use an interface to set up their strategies by dragging blocks that contain segments of a graph to create a graph to specify position or velocity versus time. When students have finished designing their path, they must click the "Run" button to launch their plan. As the plan is launched, the players can watch as the plan unfolds in terms of the game character's motion on the map as well as in the formal representations.

In this study, we used two different versions of *SURGE Symbolic.* These two versions provided different types of internal scaffolds to students. The purpose of this study is not so much to compare which version of the game "worked better," but rather the purpose was to explore how students made use of these various internal scaffolds as well as external scaffolds in the classroom, such as the teacher and the other students. The two versions of the game were very similar and differed only in the way that students controlled the game character and generated the graphs to design their path on a subset of the levels. In each level, students attempted to create a path for Surge to avoid the electricity zones and make it the exit portal. In one version, called block level (BL), students first used a toggle button to set Surge's initial position (**Figure 1**). Students then constructed position or velocity graphs to control Surge with "blocks" representing segments of the graph. Students could organize the blocks in any order to create a graph, and students could swap blocks in and out of the graph. In the second version, called worldview (WV), players used the block interface on most levels, but used a different control interface on a subset of levels. In the worldview subset of levels, players clicked and dragged Surge to create a sequence of positions to which Surge would move over the course of the level (**Figure 2**). Thus, the player specified where Surge should be at each second during the level. In both versions, the level goals and parameters (starting position, exit portal position, required velocities) were identical for each level so that students playing each version had to pass the same challenges in order to progress in the game. While the BL version exclusively had students drag blocks to create a path, the WV version used both block levels and worldview levels. Whereas the block interface focuses on connections between graphs, the WV interface was designed to help students develop understandings of the connections between the graphs and the motion of the avatar, Surge, herself. Through designing the worldview interface, we, therefore, hoped to help students develop a more intuitive understanding of the nature of motion communicated by the various relationships communicated in the Cartesian graphs.

3. Methods

3.1. Setting and participants

The study was conducted in a suburban school with 98 students in six sections of an STEM class spanning seventh grade (N_7 = 51) and eighth grade (N_8 = 47). The teacher of the class, Mrs. L, was a veteran teacher and had worked with the research team in previous years to pilot earlier versions of the game in her classroom. During the study, she walked around the classroom to assist students as needed with questions about the game or science concepts. The research team addressed only technical difficulties that students encountered during game play and recorded field notes of student game play and discourse. They intentionally did not provide assistance to students regarding conceptual questions or hints on how to solve levels.

The study lasted for six consecutive school days. Students took a pretest on the first day to assess prior understanding of concepts such as position and velocity, as well as interpretation of position-time and velocity-time graphs of an object's motion. They played the game for the next three and a half days. At the end of game play on the fifth day, students took a posttest that was identical to the pretest. On day 6, students talked with the research team about their perceptions of and struggles with the game and questions on the posttest.

Before the study began, Mrs. L's classroom was arranged in traditional rows of desks all facing the front of the classroom. For this study, Mrs. L chose to rearrange the desks into groups of four that were facing each other. As students entered the classroom on the first day of the study, students were allowed to self-select into groups. Approximately half of the groups were assigned to play the BL version, and the other half of the groups were assigned to play the WV version. Students in each group were encouraged to talk to each other for help, but groups were not allowed to talk to other groups since they were playing different versions of the game. **Table 1** shows the number of students and groups in each class period.

3.2. Data collection

Data collected for this study included pre-post scores and detailed daily field notes. Due to school district rules, video data collection was not allowed, so the researchers circulated around the room during game play taking copious notes of student game play, including student talk, teacher talk, observations of silent game play, and level completion for each student at the end of each class period. One researcher primarily focused on interactions between the teacher and students, while the second researcher focused on student talk among the groups. The researchers compared notes at the end of each day, discussed any observed patterns, and subsequently adjusted the focus of observations for the following day. On day 3, one of the researchers talked with each group in five of the six classes about how they worked through the struggles encountered in the game and how they worked together as a group. No group interview data were collected in period 6 because students in this class discovered a previously unknown bug in the game that allowed them to "complete" levels without actually solving them. Several students in this class used the bug to make progress in the game instead

Class period	**Grade**	**Number of students in each class**	**Number of students playing BL version**	**Number of students playing WV version**
Second	7	15	N_{2BL} = 7 (2 groups)	N_{2WV} = 8 (2 groups)
Third	8	14	N_{3BL} = 7 (2 groups)	N_{3WV} = 7 (2 groups)
Fourth	7	17	N_{4BL} = 7 (2 groups)	N_{4WV} = 10 (3 groups)
Fifth	7	19	N_{5BL} = 9 (3 groups)	N_{5WV} = 10 (3 groups)
Sixth	8	13	N_{6BL} = 5 (2 groups)	N_{6WV} = 8 (3 groups)
Seventh	8	20	N_{7BL} = 13 (4 groups)	N_{7WV} = 7 (2 groups)
Total		*98*	*N_{BL} = 48 (15 groups)*	*N_{WV} = 50 (15 groups)*

Table 1. Number of students and groups playing each version of *SURGE Symbolic*.

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of soliciting help to work through challenges. Because this shortcut prevented them from working together in the same way as other classes, no group interview data were collected in this class period.

3.3. Data analysis

Data analysis included quantitative comparison of pre-post scores using paired t-tests and qualitative analysis of the field notes using inductive thematic analysis [18, 19]. Qualitative data analysis began by reviewing all field notes in order to become familiar with the data. We first coded the data to identify all instances of student talk and teacher talk recorded in the data. Since we were particularly interested in how students interacted with each other during game play and how they were making sense of the game and embedded physics concepts using the designed scaffolds, we made a second pass to identify instances when students were observed using or talking about the internal scaffolds or science concepts embedded in the game and when students were interacting with each other during game play. We also closely analyzed student responses to the researcher's question about types of help they used in the game and how the groups interacted with each other.

In order to identify themes in the data, we developed an initial open coding scheme for the data using the constant comparative method [20] and iteratively applied these codes to data, revising codes and grouping codes together as needed. Specific codes included such things as use of the level map, use of help screens, student talk about mechanics of the game (i.e., how do you reset the level?), student talk about the help within the game (i.e., what does that map show?), student talk about concepts in the game (i.e., the farther apart the dots, the faster Surge goes), teacher talk about concepts or game mechanics, attempts to seek help from a peer, and attempts to seek help from the teacher. Once the codes were applied to the data through an iterative process, we searched for themes among codes. Themes that emerged from this analysis centered on the use of both internal and external scaffolds to make sense of the game and progress to higher levels. These themes are examined in greater detail in the following section.

4. Analysis and findings

To provide a backdrop for our analysis of how students made use of internal and external scaffolds during game play, we first analyze the pre-post scores. We then proceed to the focal analyses of how students made use of the internal and external scaffolds.

Analysis of pretest and posttest scores showed that students made gains in conceptual understanding of formal representations after playing the game. Paired t-tests compared pretest scores ($M = 47.0$, $SD = 19.9$) to posttest scores for all students ($M = 53.5$, $SD = 21.7$). These results showed that students made significant, albeit modest, gains in the posttest scores ($t(97) = 3.79$, $p < 0.001$) with an effect size of 0.31 and suggest that the game did indeed help students develop a better understanding of the target physics concepts in the game. Independent t-tests were also conducted to compare changes in pre-post scores for the BL group ($M = 6.1$, $SD = 17.0$) and the

WV group (M = 6.8, SD = 17.0), as well as changes in pre-post scores for seventh graders (M = 5.9, SD = 14.2) and eighth graders (M = 7.1, SD = 19.6), but no significant differences were found between either of the two groups ($t(96) = -0.19$, $p = 0.85$ for BL and WV groups; $t(96) = -0.36$, $p = 0.72$ for seventh and eighth grade groups). These results suggest that while the game did indeed help students develop a better understanding of the target physics concepts in the game, the differences in interface and representational design between the BL and WV groups did not significantly affect pre-post scores. Additionally, both seventh and eighth graders experienced similar amounts of growth in the pre-post scores. **Table 2** shows the mean scores for each subgroup.

Against this quantitative backdrop, we now shift the analysis to students' use of internal and external scaffolds during game play. We will illustrate the themes that emerged through this analysis by focusing on one group of four eighth grade boys in period 2. This group was chosen because the four members all interacted with the game in different ways, seeking help from different sources, yet very actively interacting with each other. All of the group members were also very verbal and articulated their group interactions in great detail, thus allowing for robust data collection in the field notes. We will use this group to provide examples of how they differentially leveraged internal and external scaffolds to help them progress through the game, and we will also include data from other groups to provide examples of additional instantiations of these themes.

The members of our focus group were Dylan, Connor, Preston, and Grant (pseudonyms). The four boys approached their game play in different ways. **Table 3** shows the performance of each group member on the pre and posttest, as well as the levels completed on each day as a way to show the different rates of progression through the game. Dylan was the first group

	Pretest mean score (%)	Posttest mean score (%)	Change in mean score (%)
Total (N = 98)	47.0	53.5	+6.5
Seventh ($N_7 = 51$)	43.5	49.4	+5.9
Eighth ($N_8 = 47$)	50.9	58.0	+7.1
WV ($N_{WV} = 50$)	45.5	52.3	+6.8
BL ($N_{BL} = 48$)	48.6	54.8	+6.2

Table 2. Mean average scores for pretest and posttest.

	Level at end of day 1	Level at end of day 2	Level at end of day 3	Level at end of day 4	Level at end of day 5	Pretest score (% correct)	Posttest score (% correct)
Dylan	20	57	66	Finished	Finished	95	100
Connor	14	41	60	66	Finished	65	80
Grant	11	38	51	61	64	30	35
Preston	10	34	44	50	50	75	35

Table 3. Levels completed at the end of each day of game play and pre-post performance for focus group.

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member (and the first person in all six class periods) to successfully complete all 66 levels in the game, and Connor finished all the levels shortly after he did. Both Dylan and Connor had participated in a research study the previous year with the same teacher that involved playing a different but related game, so their quick progression through the levels could be attributed, in part, to their prior exposure to a conceptually integrated game involving graphing and physics concepts. However, the design of the game for this study was significantly different from the game they played last year and presented conceptual challenges for them to navigate, as evidenced by their use of internal and external scaffolds during game play. Grant and Preston had no prior experience with games similar to this one.

Figure 3 shows a diagram of the seating positions of this group. All fours desks were facing toward each other to facilitate group conversation. While Dylan interacted with the group on multiple occasions, he was largely quiet as he intensely focused on solving his own levels as quickly as possible. In contrast, Grant, Preston, and Connor were consistently talking during game play, sharing ideas with each other, asking each other questions, and making general comments about their impressions of the game.

4.1. Internal scaffolds

In the context of this paper, internal scaffolds are supports that are embedded within the game that are designed to foster students' conceptual understanding of Newtonian kinematics and intended to help students make connections between the informal context of the game and the formal physics vocabulary and representations used to describe motion of objects. These scaffolds include help screens and hints (**Figure 4**) when a student fails to solve a level, as well as tutorials that provide new information (e.g., explanations of formal physics representations like graphs and dot traces) for future levels. Students had the option of using these supports at any time during game play, and we observed numerous students utilizing these in-game scaffolds when seeking help to pass levels, as evidenced by numerous observations of students reading help screens before starting levels, clicking on hints after failing a level, or making comments about the help screens. Some students continued to use these internal scaffolds exclusively as their help source throughout their game play. However, many students found these internal scaffolds to be insufficient when the game grew more complex.

One internal scaffold that many students appeared to use productively was the level map, which could be toggled on and off by students (**Figure 5**). This map showed Surge's required

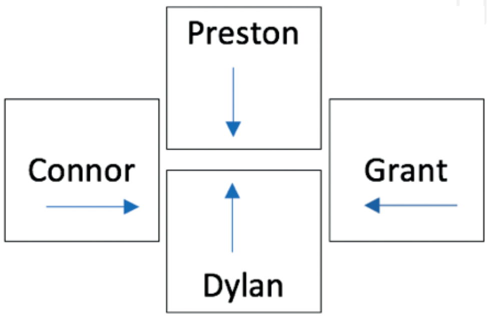

Figure 3. Group seating positions of focus group students, including direction desks are facing.

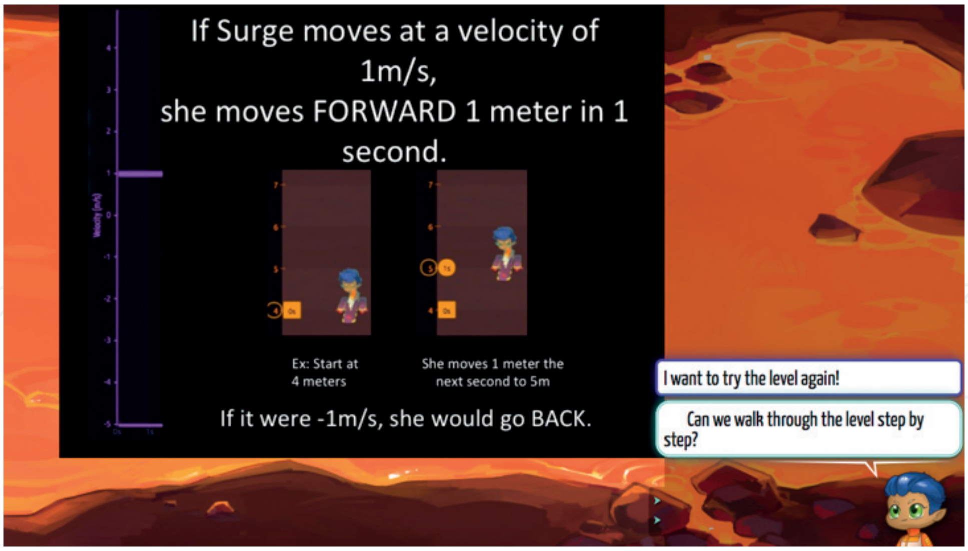

Figure 4. Sample help screen after student fails a level.

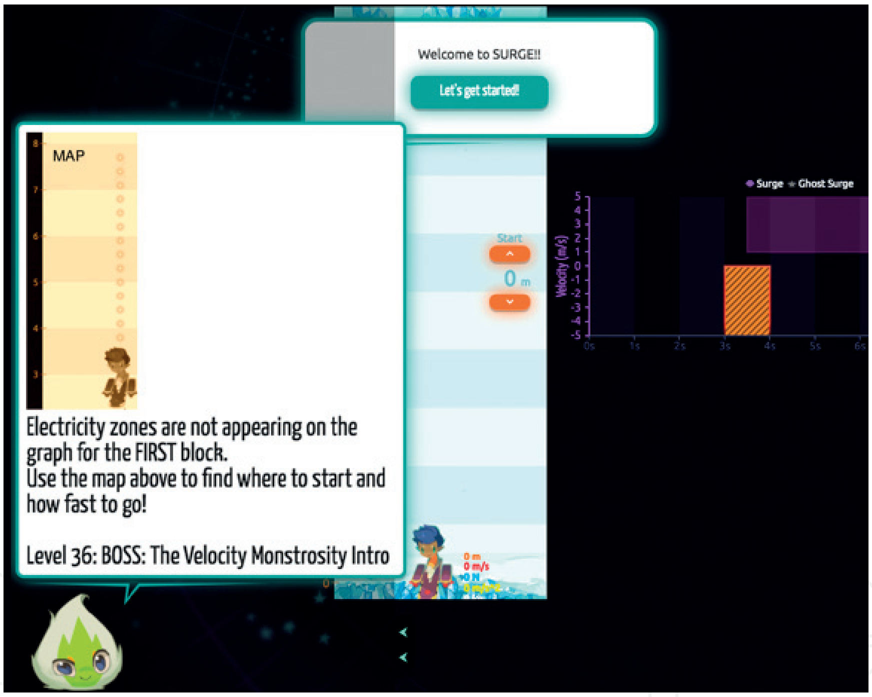

Figure 5. Level map showing starting position and dot trace.

initial starting position, as well as a dot trace to determine the necessary initial velocity for Surge to avoid a deadly electric field. Observation of student game play showed that students quickly learned how to determine the initial starting position from the map. However, many had difficulty interpreting the distance between dots as an indicator of Surge's speed and translating that speed to a meaningful slope on the graph. Field notes indicated that students who only used the level map to obtain starting position and did not use the dot traces to determine velocity often adopted an unproductive "guess and check" strategy to solve the

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level. For example, one student in period 2 was observed attempting level 19 numerous times. The student was seen viewing the level map and then moving Surge to the correct starting position, thus indicating a correct interpretation of required starting position from the map. However, he then appeared to guess as to which initial speed he needed to start, trying various speed blocks and failing the level several times before finally discovering the correct block to use through trial and error. While this student successfully determined the starting position using the map, he failed to notice or interpret any information about the required starting speed from the same map. Another student commented in the debrief session after game play that "the [map] wasn't very helpful. It told you the start position, but didn't say how fast it should be going each time," indicating that the student failed to understand that the dot traces could be used to determine the correct starting speed. Yet another student was overheard commenting on the map saying, "It says to notice the dots in the map. There are no dots on the map!" Apparently, this student never even noticed the dots on the map, much less made a connection between the dots and velocity.

Others who used the map for both starting position and initial velocity appeared to solve levels more quickly and demonstrated a stronger understanding of the targeted concepts in the game. An example of this usage can be seen in our focus group where Grant attempted to solve Level 19. He skipped through the explanation screens at the beginning of the level, looked at the map, and correctly moved Surge to a starting position of 8 m. However, he chose an incorrect initial velocity block, causing Surge to crash and fail the level. Reading the hint block, Grant exclaimed, "Too slow! What?!?!" He then enlisted the help of another member of his group, Connor, to figure out how to solve the level. Connor came over to Grant's chair to look at his screen and asked, "Where does the dot trail start?" Grant answered, "8." Then, Connor replied, "Good. How are the dots spread out?" In this exchange, Connor tried to get Grant to notice the dot traces and use the spacing between the dots to determine if he needed to start at a slow speed or a faster speed. In another example, Connor used the dot traces to calculate the initial velocity he needed for a level. While looking at the level map showing dots spaced far apart and thinking aloud, he said, "That [spacing] is like big. 4 per second-ish." He then chose the 4 m/s block and successfully solved the level. Connor demonstrated his understanding of how to use the spacing between the dots to determine his initial velocity, seemingly understanding that the farther apart the dots are, the faster the speed.

Dylan also demonstrated using the map for information on both starting position and velocity. In one instance, he noticed Grant struggling to solve a level. Dylan looked at Grant's level map and told him to start at 4. Then Dylan said, "the dots are close together. 4 s. You need to make her go forward in 4 s." In this exchange, Dylan demonstrated that he was using the map for information on both starting position and velocity. Not only did Dylan and Connor finish all the game levels before anyone else in the class, they also scored high on the posttest at the end, demonstrating strong conceptual understanding through their game play performance and scores on the posttest. While Dylan started with a high pretest score, Connor had one of the larger gains across all the classes, possibly suggesting that his interaction with the game helped him make sense of the science embedded within the game. His gains could also possibly be attributed to his close proximity and access to Dylan, a student in his group who had a more sophisticated conceptual understanding of the science and math ideas in the game, as evidenced by his high pretest score.

Unlike other members in the class, Connor had the opportunity to tap into Dylan's expertise and use him as an external scaffold during game play.

4.2. External scaffolds

Although most students used internal scaffolds in some way to assist their game play, many also found that these scaffolds were not enough to get through challenges. They quickly sought help from external resources available to them outside the game to help them advance in the game. The source of information they needed to make progress came from various people or resources outside the game, what we are calling "knowers." Students chose to seek help from the teacher, each other, and even other tools and materials to reason through the math and science needed to pass a level.

We noticed that the type of *knower* students sought out and the nature of the questions they asked varied by student. Students who primarily wanted to pass levels but did not care as much about the reasoning behind their success or failure tended to solicit assistance that would help them advance in the moment on a particular level. Students who were motivated by this type of help possessed what we termed a "game play orientation." Students who wanted to make sense of the rules and strategies behind Surge's movements often sought help to reason through the math and physics in the game. We refer to this as a "sense-making orientation." We have observed related patterns in studies with other games (e.g., [17]).

An example of these orientations can be seen in the focus group. Preston's game-play orientation was evident from the beginning when he approached the game from the perspective of a kid playing a video game in an informal setting. He quickly jumped into the storyline of the game and was primarily concerned about saving "fuzzies" and unlocking new settings (i.e., "Oh, there's SNOW!!"). At some point in his game play, however, he got somewhat frustrated that he could not do more with the rescued fuzzies. He made the least progress in his group and actually showed losses in his posttest score. He never tried to make sense of the math or science behind the game level, admitting in the whole class debrief at the end of the study, "I'm going to be honest. After taking the post-test, I didn't feel I learned anything. I was focused on beating the game." Dylan, however, demonstrated a sense-making orientation, as illustrated on day 2 when he worked through a level and failed. We observed him reading the feedback, presumably to reanalyze his approach. After he thought about it, he said to the computer, "Oh, OK," and succeeded on his next attempt. Dylan's repeated attempts to integrate the feedback indicate that he was trying to make sense of Surge's movements and using the game feedback to inform his next strategy.

With either orientation, students identified different *knowers* in the learning environment when they wanted help to make progress toward their goal. We conjecture that an individual student's orientation toward the game influenced the nature of questions asked and the type of *knower* they sought for help. In this study, we surveyed each student that was present on day 3 of game play and asked how they typically got help when they encountered a sticking point in the game. All students first responded that they started with internal scaffolds within the game. When the game did not provide the help they needed, some of them identified four categories of external scaffolds, what we are calling in this case *knowers*, that they turned to for

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Type of knower	Second Period	Third period	Fourth period	Fifth period	Seventh period	*Total*
Game as knower	2	3	2	4	4	15
Self as knower	2	4	1	2	2	11
Peer as knower	9	7	10	7	14	47
Teacher as knower	2	0	3	1	1	7
Total	15	14	16	14	21	80

Table 4. Type of knowers used by number of students per period.

further help. While some students explained that they had a chain of knowers they could go to next if one failed, **Table 4** identifies the *first knower* each student would seek when the Surge's internal scaffolds no longer provided the help they needed.

4.2.1. Game as knower

Students who identified the "game as knower" were students who showed little or no use of external scaffolds. They leaned on the internal scaffolds to help them figure out what to do: they would revisit earlier levels of the game to help with later levels, repeatedly consult help screens or hints, or write down notes from the help screens. There was little audible or visible evidence of the use of this scaffold, but students self-reported these behaviors when speaking with researchers. In the focus group, both Dylan and Preston were classified into this category as they rarely, if ever, sought help from an external scaffold and relied on the game to help them progress through levels. However, since Dylan possessed a sense-making orientation, while Preston demonstrated a game-play orientation, their interactions with the internal scaffolds looked different, as described previously. Students in other groups showed their reliance on the game as knower in a couple of different ways. One boy said that when he gets stuck, he generally, "tries a couple of levels before" his current level to review any instructions that he might have gone through too quickly or to see if the earlier levels could provide some guidance that he did not pay enough attention to earlier. Another student described how he would copy and paste the help tips into an internet browser so he could flip back to see them when he got stuck. For some students, these strategies suggest they are applying knowledge of games outside the classroom to be successful with this game. For example, students who are familiar with games may expect help features within the game to provide all the assistance that is necessary to succeed with game play. One boy had such high expectations that the game was going to help him advance that he "sat a full period on one level trying to use the game to help get through the level." He thought it should have been easy and was "too embarrassed" to ask for any external help to get through the level. He kept reading the help in the game but did not understand what it was telling him to do. No students in his group nor Mrs. L knew that he was stuck for a full class period.

4.2.2. Self as knower

The "game as knower" strategy is closely connected to the "self as knower" strategy and is sometimes impossible to tease apart. There were a few students who showed visible evidence beyond the screen that they were doing something more in the game than just getting through levels. Students who fell in this category often used the feedback and help from the game to then integrate their prior knowledge of math and physics before deciding on their next strategy. These students worked through the challenge on their own, often succeeding with just the help suggestions within the game. Yet, there were times they tapped into external tools or representational resources, such as paper and pencil to extend graph lines, to help them with their sensemaking. Thus, the students who fell into the "self as knower" category and made their math and science thinking visible were students who had a sensemaking orientation. For example, while a level was running, one student moved her arms in gestures that mirrored the graph lines that were being generated in the game. When Surge crashed, she froze her arms, and reacted, "Oh…The down is not right. I've got to keep going down, down, down. Gosh!" She reshaped her arms while talking this through to imagine what move she needed to try next. A few students used paper to do some inscriptional work with mathematical notations that were not in the game or modified representations in the game by using extra paper to stretch graph lines to better obtain data. For example, Connor used an index card to mark a dot on one card that he held up to a graph, and then he moved that card up to the graph above it, demonstrating his strategy of coordinating information across graphs to inform his next move. While it is difficult to identify students who rely on their "self as knower" versus the "game as knower," we did notice that the students who did extend their reasoning beyond the game often advanced to higher levels in the game more quickly and had either greater gains or higher posttest scores.

4.2.3. Peer as knower

Students who used a "peer as knower" identified someone in their group to ask for help to solve levels. It was not always any member of the group who could serve as the knower, however. Students had multiple reasons for selecting different peers. Sometimes, the same student would call on different peer knowers for different reasons. For example, Grant positioned Connor and Dylan as his knowers at different times. Initially, when he asked for help, he adopted a game play orientation to help him get through a level. He asked Dylan how to get through a level and was happy with a response to "start at 4." Yet, when that did not work moving forward and he realized that he was still getting stuck in the same part of each level, he took on more of a sense-making orientation when he asked Dylan, "How do you know where to start *in general*?" Here, he was trying to uncover the strategy behind getting started with each level, not just the number where he needed to start in order to pass that particular level. Later, when Grant realized that Dylan was so far ahead and working with the game in his own way, he called on Connor when he needed help making sense of the dot trace map. This was interesting because Preston and Dylan were the peers closest in proximity (see **Figure 3**), but Grant recognized that the two of them had their own game play strategies that would be interrupted if he asked a question. He knew Connor was ahead of him, but closer to his own level than Dylan, so he asked Connor to physically walk around to his computer and help him. Here, we see an example where the group member that was the farthest along in the game (Dylan in this case) was not always positioned as the knower in the group. Many students responded that they preferred to get help from a group member that was just slightly ahead of them in the game instead of the student who was several levels ahead.

In this group, Grant selected his peer knower based on what he needed—a quick response to get through a level, or someone who could spend more time with him to make sense of the level. Other students had different reasons for calling on different peers. Some students identified a *partner as knower*. Early on in game play, there were some groups where two or more members explicitly decided to work through each level together. They often repositioned their desks so they could more easily see each other's screens, or they engaged in more talk-alouds while they were making decisions on how to proceed in a level. These groups tended to move relatively slowly through game play, making sure that each member in the partnership was progressing. For example, there were times when one member had a lucky guess that allowed him to pass the level, but he struggled to get his partners through the same level because he did not have sound reasoning. But, he would not move on to the next level until his other partners were with him. In general, students that worked in partnerships would hang back with the slowest member to work together to identify the inputs that would yield successful outputs.

Other groups just said "*anyone in the group*" would serve as their knower. In these groups, each individual worked independently. If one student got stuck, he or she said something like, "Did anyone get through level 21? How did you do it?" Any member of the group could respond at any time. Sometimes it was an individual who recently completed the level. Other times, it was a student who was willing to take the time to work through a level with someone else.

Finally, some groups had one student who would serve as the knower for anyone in the group. In one group, when the students were asked who they go to for help, they all identified the same *individual in the group*. He also identified himself as the group knower. When pressed on playing this role, he responded, "it is just what I do." Apparently, in this class and others, he is perceived as a "knower" by his peers, and he is comfortable with this role.

We also observed what we termed "*reluctant peer knowers*" in a group, which is someone that a group member calls on for help, but is reluctant to help because he/she would rather play his/her own game. Reluctant knowers often gave short tips like, "Start at 4," with no reasoning, as Dylan did for Grant in an earlier example. They would provide some assistance, but it was often terse and more of a cheat. Reluctant knowers sometimes took a group member's computer and did the level for them, or simply turned their computer around to show a level solution to help the other member. If their help did not work, they most often did not spend any more time trying to help the student who asked for assistance.

Whether reluctant or not, the peer as knower group was the external help that most students turned to when they got stuck in the game. It seems that working in groups, or just having the ability to talk to peers when needed, is an external scaffold to game play that students are comfortable using for assistance. Students respond well to the peer feedback, and this keeps them engaged in game play by helping them work through obstacles collaboratively.

4.2.4. Teacher as knower

A final category included students who identified their "teacher as knower" and repeatedly asked Mrs. L for help. This group included students who first tried to work with the internal scaffolds of the game, still got stuck on a level, and immediately turned to Mrs. L to help them work through the challenge. These students rarely consulted with their group members, preferring instead to work exclusively with Mrs. L. Students in this category indicated that they went to Mrs. L because she could "explain it better" than anyone else or that they liked to problem-solve with her. In our focus group, no one solicited help from Mrs. L. but we did see a few examples of this from other groups, particularly in earlier levels of game play. It was clear early on that Mrs. L. did not have the quick answers to help students get through levels, but she was willing to pull up a chair and work alongside students to beat a level. One girl happened to be in a group where the other members all missed a day and she ended up being many levels ahead of her peers. Thus, because she did not feel she had a peer in her group who could help her with the game, she instead went straight to Mrs. L. for help.

Mrs. L. knew enough about the game to get through the early levels easily. Still, when students asked for help on these early levels, she did not give them a direct answer to their questions. Instead, she pressed their reasoning and encouraged them to try different options. Whether their attempts failed or succeeded, she then encouraged them to reflect on what they did to make sense of the failure or success. She spent a lot of time with students when they requested help in the early levels. As the levels got more complex, she tended to hover over a student and watch their game play decisions, but she asked fewer questions and interacted on the whole much less frequently with students. This could be one reason why more students did not call on her for additional help and instead chose another strategy—either within the game or asking a peer for help.

5. Discussion

While digital games for learning have been shown to support students' conceptual development in science, they have not been widely adopted in classrooms. This paper explores how students used the internal scaffolds in the game and external scaffolds provided by other knowers in the classroom to successfully play a game for learning physics. A key finding, while not surprising, was that not all students engage in game play in the same manner. Some students approached the game from a game-play orientation where they were simply focused on solving levels, while others approached the game from a sense-making orientation where they sought to truly understand the target concepts and formal representations.

In this study, most students started within the game to find the help they needed to advance in levels. When they ran into a need for help, their game-play orientation influenced who they turned to and for what reason. Whether they turned to their own ability to make sense of the game, requested help from a peer, or solicited Mrs. L's help, this classroom game play experience provided students with opportunities to locate the help they needed when they needed it. External resources, from paper to peers, were accessible by all students. Even the desk arrangement, from traditional rows in their typical class sessions to groupings of four for the game sessions, seemed to be an invitation for students to work together. Communication among peers was clearly encouraged.

These findings have important implications for how teachers design a game play learning environment in their classroom. Physically, different arrangements of furniture, particularly when computers are used, imply different kinds of participant structures. Teachers should consider what kind of access they want their students to have to external scaffolds, including their peers, during game play. Teachers also need to be aware of different orientations that students may adopt during game play and how their stance may influence how they are attending to the conceptual underpinnings of the game. This could mean that teachers take an active role during game play to facilitate connections between the game and science learning either through intentional discourse with groups or in whole-class instruction interspersed throughout the game play period. This kind of discourse can be invaluable to foster the necessary science thinking during game play. Research has shown that students can get very distracted while *doing* a particular activity and forget to attend to what they are supposed to be *understanding* [21]. In a game play, this same stance can happen, particularly for students who have a game play orientation like Preston and who are very concerned with beating the game, but not learning along the way. Teachers can play a role to facilitate the game-to-science content connection for students. Allowing students to work in groups, even if they are playing the game individually, encourages students to talk, which allows their thinking to become visible [22]. Teachers can use this talk as a formative assessment opportunity to identify ideas that need to be addressed and questions that can be asked to deepen student thinking [23]. Leveraging effective teaching practices with the affordances of digital games for learning can potentially lead to rich, meaningful student engagement with scientific ideas.

We believe this paper also has implications for the designers of future games for learning. In our study, we noted the crucial role that external scaffolds played in most students' game play experience. While some students relied exclusively on internal scaffolds and their own prior knowledge and resources, many students preferred to seek help from a peer or Mrs. L. We think game designers should consider the social capital present in most classrooms and leverage the discourse that will likely emerge when games are played in a traditional K-12 classroom. This could take the form of online discussion forums or embedded videos that serve as a virtual teacher and explain challenging concepts within the game.

This study has provided an examination of what DIG game play looked like in real classrooms. While much needs to be learned, this study showed that the DIG itself provided a goal (whether that goal was just to beat a level or a deeper goal of making sense of the character's motions and learning more about math and science in order to pass a level). Progress toward the goal was interrupted by challenges, also presented by the game. When these challenges proved too difficult to overcome, students sought help, and this is where the game extended its reach into the classroom context. Understanding more about when students are reaching for help, who they are turning to, and what kind of help they are seeking can help game designers and teachers learn how to design effective learning environments that support game play in secondary science classrooms. Essentially, while much research on the design of scaffolding in games for learning has focused on internal scaffolds, future research on external scaffolds may prove much more productive, with the added bonus of potentially even greater generalizability.

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