Chapter # - will be assigend by editors

SUPPORTING LEARNING IN EDUCATIONAL GAMES: PROMISES AND CHALLENGES

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Abstract: Digital, educational games have many promises (e.g., increasing students' content knowledge as well as competencies like problem solving, spatial skills, and persistence). However, there are challenges to overcome before using these games more broadly in educational settings. One challenge involves identifying effective, theoretically-based learning supports that do not reduce the fun/engagement inherent in gameplay. In our chapter, we focus on the design, development, and testing of various types of embedded learning supports (e.g., animations, worked examples, formulas, interactive definitions, and videos). We contextualize this discussion in terms of our ongoing research with the game *Physics Playground*, currently being tested with middle- and high school students. We additionally elaborate on some of the challenges that we, as well as other educators and educational game designers, have faced in the design of optimal supports, concluding with ideas for future research.

Key words: learning supports, instructional supports, digital games, educational games, Physics Playground, stealth assessment.

1. INTRODUCTION

"Play is our brain's favorite way of learning things." —Diane Ackerman

Can playing digital games enhance learning? This rather general question has been investigated in many research projects over the past couple of decades using various games that support different competencies, such as visual-spatial abilities and attention (Green & Bavelier, 2007, 2012; Shute, Ventura,

& Ke, 2015), persistence (Ventura, Shute, & Zhao, 2012), creativity (Kim & Shute, 2015), and civic engagement (Ferguson & Garza, 2011). Also, many research studies have used digital games to enhance students' knowledge about particular concepts like physics (Shute, Ventura, & Kim, 2013), mathematics (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Ke, 2008), and ecosystem science (Kamarainen et al., 2013). Most of the research on the effectiveness of digital games to support learning have shown positive results (Clark, Tanner-Smith, & Killingsworth, 2016; Gee, 2003; Ke, 2013). For instance, Clark and colleagues (2016) found, overall, a medium effect size in a meta-analysis comparing the use of digital games and nongame conditions relative to their effects on learning. The effectiveness of the games in supporting learning, however, depends on certain features of games.

As Shute and Ke (2012) pointed out, well-designed games include the following features: (1) ongoing interactive problem solving; (2) specific goals or rules which help the player focus and stay motivated to play; (3) adaptive challenges which keep the level of difficulty of the game in and around the outer boundaries of players' ability—as the player gains new skills and becomes more capable, the game's challenges become more difficult; (4) control by the player of game play, the game environment, and/or the learning experience; (5) ongoing and timely feedback; (6) uncertainty, which makes the game interesting, entertaining, and unpredictable; and (7) sensory stimuli which refer to a system of various media, e.g., graphics, sound, and animation, as well as a possible storyline which can keep the player on edge and immersed in gameplay. Because games differ in terms of their quality, not all games can enhance learning, thus our focus in this chapter is on the effects of well-designed games as learning environments (Ke, 2016; Wouters & van Oostendorp, 2013) or as vehicles that can be used to enhance learning (Gee, 2003).

Well-designed games also benefit from particular learning theories (Gee, 2008). For example, when playing digital games, players are actively involved in solving specific problems (sometimes in collaboration with other players). In such cases, we can see the common elements of constructivist learning, collaborative learning, and situated learning theories (Bruffee, 1993; Lave & Wenger, 1991; Leemkuil & de Hoog, 2005). Moreover, the incentive systems embedded in the games (i.e., the reward and penalty system in the games; the collection of coins, trophies, badges) are supported by basic behaviorist learning theories (Skinner, 1978). Learning theories support how learning occurs in well-designed digital games.

Another important factor that makes digital games potentially valuable learning tools has to do with how popular they are among the people around the world regardless of age, gender, and ethnicity. For example, 97% of children and adolescents in the United States play a type of digital game for at least one hour per day (Granic, Lobel, & Engels, 2014), and 42% of Americans play video games regularly, or at least three hours per week (Entertainment Software Association, 2016). Why are digital games so popular? The short answer is that they are fun and often immersive (Prensky, 2001)—either played alone or with others. Specifically, playing well-designed games can lead us to a state in which we lose track of time, and experience strong positive feelings when solving difficult problems ("aha" moments). This state is called *flow*, introduced by Csikszentmihalyi (1990).

Learning scientists, instructional designers, and educators have reported the potential of digital games as learning tools to support various content knowledge (e.g., physics, mathematics, ecosystems) and various competencies (e.g., problem-solving skills, critical thinking, computational thinking, and creativity). As a result, new fields are emerging, such as game-based learning, game-based assessment, serious games, and educational games. However, the promises of digital games for learning can fall into the trap of "chocolate-covered broccoli" (Laurel, 2001). That is, digital games with poor integration of learning materials and supports can detract from the fun, disrupt the state of flow, and turn the game into just more instructional software. This issue of optimally integrating learning supports into educational games has caught the attention of researchers and game designers. Research on best practices of incorporating learning supports in digital games—without interrupting flow while maximizing learning—and research on the effectiveness of these learning supports can shed some light on answers to the how, what, when, and how much of providing learning supports in digital games.

The purpose of this chapter is to (a) define the most common types of supports and their effectiveness relative to learning, (b) present an example of our own work implementing a learning-supports system in an educational game, (c) discuss how we handled various challenges that we faced when incorporation learning supports in our game, and (d) suggest future research that can help pave the way for more successful educational games. In the following sections of this chapter, we will elaborate on each of these topics in order.

2. COMMOM LEARNING SUPPORTS IN EDUCATIONAL GAMES

In this section we first look at the literature to see whether learning supports in educational games were effective or not. Then we elaborate eight common learning supports used in educational games.

2.1 Are Learning Supports in Games Effective in their Support of Learning?

As discussed in the Introduction, and based on a couple of decades of research in game-based learning, educational games are generally viewed as effective learning tools (e.g., de Castell, & Jenson, 2003; Gee, 2003, Prensky, 2001). But what, specifically, is the effect of including explicit learning supports in these games? Wouters and van Oostendorp (2013) define such supports in educational games as comprising multiple methods and techniques that help to develop learners' cognitive activities during gameplay.

The literature on learning supports in learning environments in general is somewhat conflicted. Some researchers (e.g., Black & Deci, 2000) note that learning environments that allow for full autonomy (i.e., student control), without explicit supports, can be more engaging and effective environments than those without such freedom. Also, Clark, Tanner-Smith, and Killingsworth (2016) concluded from their meta-analysis that extra instruction (after gameplay, in the form of learning support) did not produce any significant learning differences between game and non-game conditions where compared.

More specifically, regarding educational games, other researchers (e.g., Wouters & van Oostendorp, 2013) have concluded that to keep novice players engaged with the game, it must include learning supports. That is, digital games are complex and challenging environments that demand a lot of cognitive effort, so without any supports, learners will likely get stuck, frustrated, disengaged, and thus stop playing (Wouters, van Nimwegen, van Oostendorp, & van Der Spek, 2013). In that case, learning outcomes may be in jeopardy. Therefore, including supports in educational games increases the odds of improving learning. However, integrating supports into educational games is not easy, especially if we want them to not disrupt flow.

Regarding the effectiveness of various learning supports in educational games, Wouters and van Oostendorp (2013) conducted a meta-analysis on the topic. They selected 29 studies (with 3,675 participants) and computed 107 pairwise comparisons to investigate the effectiveness of learning supports in educational games. They found a positive and moderately-weighted effect size of d = .34 (z = 7.26, p < .001) which suggests that the use of learning supports in games can, in fact, improve learning. Furthermore, Wouters and van Oostendorp identified 24 different types of learning supports and grouped them into ten categories. We briefly discuss eight of the more common types of support used in educational games.

2.2 Common Types of Learning Supports Used in Educational Games

There are multiple kinds of learning supports that have been used and tested in educational games and other kinds of learning environments. Here we describe a set of eight different supports that are most commonly used in educational games (Wouters & van Oostendorp, 2013): reflection, modeling, advice, collaboration, interactivity, narrative elements, feedback, and modality. Wouters and van Oostendorp included two other categories: personalization (e.g., personalized messages), and other (e.g., goal direction, background information, and cues). We chose not to include these two categories in our chapter because of two reasons. First, what we present in our own work relates to the eight categories listed above, and these two categories seem to be less used in educational games. Second, we believe that these two categories can be addressed in the other eight categories. For example, feedback and cues can be personalized.

The first type of support is *reflection*. This group of supports aims to stimulate learners' thinking about their performance and learning in the game. Research has shown that knowledge retention is improved if students are required to reflect on what they learned (e.g., Leemkuil, 2006). Some of the learning supports in games categorized under reflection include: (1) self-explanation (asking learners to explain to themselves—verbally or written—as they study a lesson/concept; Johnson & Mayer, 2010), (2) elaboration (extra task-related cognitive activities; Shebilske, Goett, Corrington, & Day, 1999), and (3) assignments (e.g., queries to find relationships between two or more variables; Leemkuil, 2006). These types of support can be implemented in various forms during gameplay (e.g., reflective questions, extra cognitive tasks, reviewing and discussing their answers/solutions). The point is that this group of supports help learners pause for a moment, analyze their answers/solutions, and use organizational and integrational cognitive processes to learn the underlying concepts within the game.

The second type of support is *modeling*. This group of supports provides an explication or illustration of how to solve a problem or perform a task in the game. The two most common supports categorized under the modeling category are: (1) scaffolding (Barzilai & Blau, 2014), and (2) worked examples (or expert solutions; Lang & O'Neil, 2008). Modeling can be provided either inside or outside of the game, by a peer, expert, or the game itself; and it can be delivered verbally, graphically, or via animated form. One possible criticism regarding the inclusion of worked examples in a game is that learners can see a solution and then replicate it without actually thinking about the underlying concepts being used to solve the problem. However, with a good reward/penalty system in place, negative effects of using worked examples can be minimized. Also, providing partially worked examples can reduce the potential negative effect of fully worked examples. This is described in more detail in Section 3 where we present an example of integrating such worked examples in our game called *Physics Playground*.

The third type of support is *advice* (e.g., Leutner, 1993), intended to guide the learner in the right direction without revealing the solution. All types of advice (contextualized, adaptive or not) that are game-generated can be grouped under this category. For example, a hint can provide the learner with suggestions about what to do next in the game, or provide an elaborated explanation about possible consequences of his/her action. Advice can consist of a short message asking the player to focus on a particular aspect of the task, or give a cue about where to start.

The fourth support category is *collaboration* (van der Meij, Albers, & Leemkuil, 2011), which may involve other players discussing the game or a particular level. Collaboration can help novice players figure out ambiguities in the game and better understand the knowledge and skills they need to learn. Many games allow for live chat and exchange of information among players. Alternatively, collaborative gameplay may be done with learners playing the game in dyads or small groups, then they can get involved in after-game discussions in online forums or in physical environments (e.g., a classroom).

The fifth learning support type is *interactivity*. This category is more focused on giving choices and control to the learners. Any type of learning support which is responsive to learners' actions can be categorized under this group. For example, Moreno and Mayer (2005) designed their agent-based multimedia game with interactivity where students, for example, had to select roots, stems, and leaves that best helped plants survive on the planet. Another group of students used a different version of the game (i.e., with no interactivity). They interacted with a pedagogical agent who simply showed them pertinent information regarding the plants. The authors found that interactivity helped students learn and retain knowledge more than non-interactivity.

Narrative elements comprise the sixth type of learning support, where content can be integrated into the storyline of a game via narratives that contain surprises, foreshadowing, and fantasies. The narrative of a game provides a cognitive framework for the learners with which they can better learn and remember the underlying concepts in the game (e.g., Adams, Mayer, MacNamara, Koenig, & Wainess, 2012). This type of support can be seen, as Prensky (2001) pointed out, in genres such as adventure games or role-playing games.

The seventh type of learning support – and likely the most powerful one – is *feedback*, especially formative feedback which is essential for learning (Shute, 2008). Given the high degree of interactivity existing in most games, feedback becomes critically important. As Shute (2008) notes, there are many types of feedback, but the two most common types used in educational games are corrective feedback (e.g., showing if an answer/solution is correct or not), and explanatory feedback (e.g., describing why the answer/solution was right or wrong). Cameron and Dwyer (2005) found statistically significant differences on all learning outcomes when feedback was included in the game versus when it was not.

Finally, the eighth support category is *modality* (Ginns, 2005; Moreno & Mayer, 2002; Ritterfeld, Shen, Wang, Nocera, & Wong, 2009). That is, learning supports can be provided via different modalities (i.e., auditory, visual, textual) and each type can positively or negatively affect learning. For example, Moreno and Mayer (2002) found that learners remembered more of the materials, achieved better transfer, and rated more favorably virtual reality environments that used speech rather than on-screen text to deliver learning materials. Also, Ritterfeld and colleagues (2009) point out that multimodality is one of the most important aspects of educational game success—providing learners with materials via different channels. Results of their study showed that multimodality positively affects knowledge gains for both short-term (at the posttest) and long-term (follow-up test) outcomes.

The foregoing learning supports can be personalized and adaptive to learners. That is, the what, the where, the how, and the when of learning supports can be tailored to the current needs of the learners as well as preferences. After conducting a moderator analysis, Wouters and van Oostendorp (2013), found out that among the 29 studies they examined, reflection, modeling, collaboration, modality, and feedback enhanced learning, but advice, interactivity, and narrative did not. This does not mean that the non-significant learning supports types will never be useful; rather, the effectiveness of all learning supports is likely dependent on appropriately integrate learning supports into educational games. In the next section, we present an example of designing, developing, and implementing learning supports in a specific educational game.

3. LEARNING SUPPORTS IN PHYSICS PLAYGROUND

As mentioned earlier, different types of learning supports tend to promote learning across educational games (Wouters & van Oostendorp, 2013). However, details about particular features and their associated effectiveness of different types of learning supports are lacking in the literature (Johnson, Bailey, & Van Buskirk, 2017; Ke, 2016). Ke and Shute (2015) pointed out that next generation of educational games will likely embody two related functions: (1) game-based stealth assessment, and (2) adaptive learning supports, which are based on the results of the in-game assessment. Effectively integrating the assessment and associated supports must rely on an iterative game design process.

In this section, we describe some of our processes related to developing, implementing, and testing various learning supports in the game *Physics Playground* (Shute & Ventura, 2013).

3.1 Original Version of Physics Playground

Physics Playground (PP) is a homemade 2D physics game designed to enhance qualitative physics understanding. In the original version of *PP*, we used stealth assessment technology (Shute, 2011) to measure player's conceptual understanding of physics related to: (1) Newton's laws of force and motion, (2) potential and kinetic energy, and (3) conservation of angular momentum (Shute, Ventura, Kim, & Wang, 2014).

The nonlinear version of *PP* had only one game type—the sketching interface. The sketching levels require players to draw simple machines (i.e., lever, ramp, pendulum, and springboard) to guide a green ball to hit a red balloon—the goal in all levels. Players can win a silver or gold trophy for solving a level, but no trophies for failures. Crafting optimal solutions get them a gold trophy.

In the *Chocolate Factory* level (see Figure 1), players who solve it within two steps get a gold trophy (i.e., drag a pin to the tree branch (Step 1), draw a ramp from the pin following the path of the dotted line (Step 2), then the ball will travel along the ramp and hit the balloon).

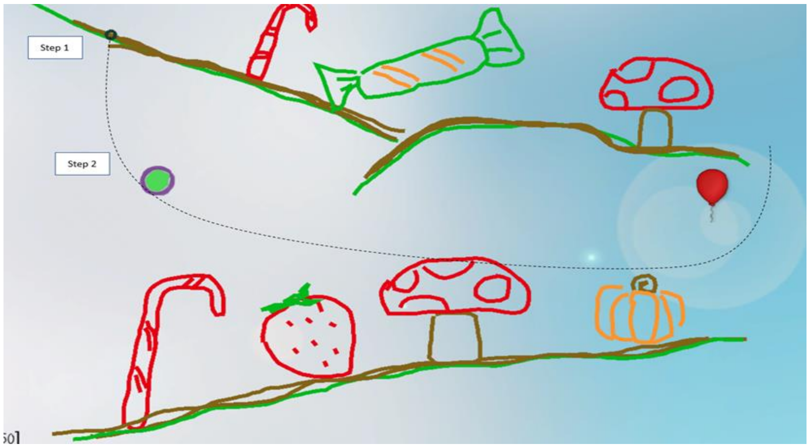


Fig. 1 *Chocolate Factory* level in *Physics Playground*

Over the past decade, we have conducted various empirical studies testing the effectiveness of *PP* on a range of competencies including physics understanding and other competencies, such as creativity and persistence. We consistently found that (1) *PP* can foster motivation and learning, and (2) the embedded stealth assessment measures are reliable and valid—significantly correlated with external measures (see Shute et al., 2015). The goal, however, was to enhance the game by including targeted in-game learning supports. This led to new funding (NSF and IES) to design, develop, and test both cognitive and affective *stealth-assessment-based adaptive learning supports* (with our focus in this chapter on the cognitive supports). Over the course of past two years, we conducted several usability studies to design a new version of *PP*. In the following sections, we first discuss the challenges we faced and decisions we made along the way. Then, we will elaborate on the current version of *PP*.

4. CHALLENGES WE FACED, AND DECISIONS WE MADE

Well-designed games and good instructional design should go hand-in-hand (Hirumi et al., 2010; Shute, Rieber, & Van Eck, 2011). But introducing learning supports in a game poses two main challenges: (1) providing appropriate support without giving away the answers (e.g., Hirumi et al., 2010), and (2) ensuring alignment between learning supports and game mechanics (i.e., game rules) without disrupting the flow (Ke & Shute, 2015), particularly since the effectiveness of the supports vary depending on the degree of cognitive load and game flow (Ke, 2016).

This section focuses on the specific hurdles we encountered and our decisions to surmount them during the development of the cognitive supports that align with game mechanics in *PP*. We describe how we sought the sweet spot between the land of theory (learning supports) and the land of data (results of several usability studies).

4.1 Early Version of Learning Supports

We adopted the physics competency model to undergird the systematic design iterations of the supports in *PP*. The early version of the cognitive supports included five different types of support (Figure 2): (1) Game tutorial, (2) Worked examples, (3) Hewitt videos, (4) Physics facts, and (5) Advice.

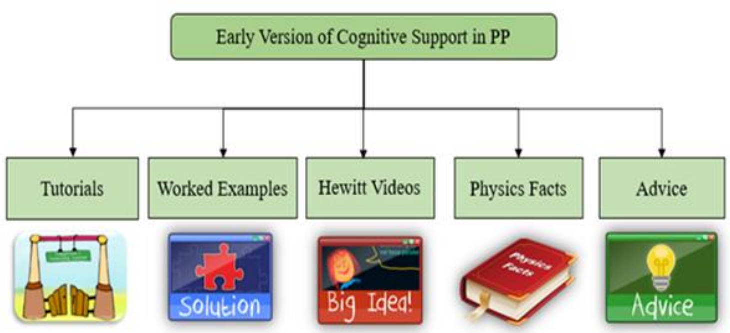


Fig. 2 First version of cognitive support in *Physics Playground*

Game tutorials resided in two separate playgrounds. The sketching tutorial playground consisted of six interactive tutorials (i.e., game mechanics, nudge, ramp, lever, pendulum, and springboard). The manipulation tutorials introduced essential game tools relevant to our new task type we developed (i.e., blower and puffer, general sliders, specific sliders, and bounciness).

In addition to the tutorials, students could access other supports in a level via the "support kit" tab located at the left-hand side of screen. Clicking on the tab opened the support menu (Figure 3). This allowed students to access physics facts, worked examples, and Hewitt videos if they were in a level playing for less than 5 minutes. The advice icon only appeared when the game detected a student was in the same level ≥ 5 minutes.

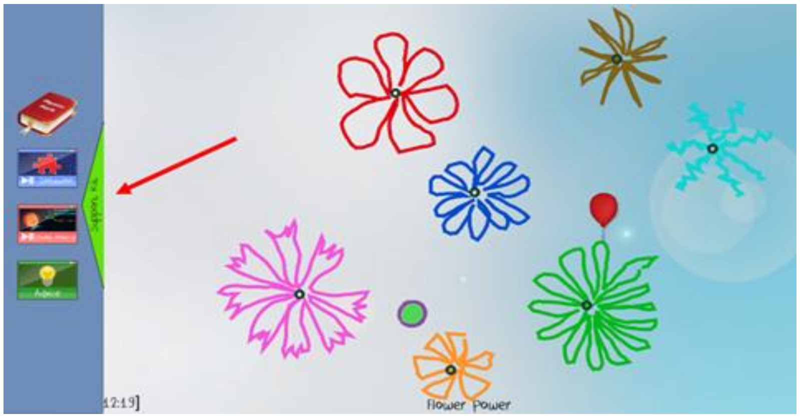


Fig. 3 Support menu in *Flower Power* level in *Physics Playground*

Clicking on the Physics facts support (i.e., the dictionary icon) led to a non-interactive list showing all the relevant terms, definitions, and short examples. Clicking on the Worked Example support (i.e., the jigsaw puzzle icon) directed students to the solution video. Clicking on the Hewitt video support allowed students to watch a physics video explaining the primary concept related to the level. And clicking on Advice (i.e., the light bulb icon) triggered a short, general hint for solving a level (e.g., "Remember that a larger force will cause an object to accelerate faster").

4.2 Usability Study 1

To examine the effects of the five cognitive supports and our new task type (e.g., manipulation levels), we conducted the first usability study at our laboratory school, Florida State University School (FSUS) at the end of the first year of the project. FSUS is located in Tallahassee, Florida, in an urban/suburban setting. It is a K–12 school whose heterogeneous student population represents Florida's population demographics (50% white, 29% African-American, 12% Hispanic, 5% Multicultural, 3% Asian, and 0.2% Native American). In FSUS, 21% of middle school students and 11% of high school students are enrolled in the free and reduced lunch program. Recruitment occurred via science teachers in their classes, and flyers at the school.

In the 3-day study, we observed and interviewed 24 9^{th} to 11^{th} grade students, who were either paired or played individually for a total of 150 minutes. On day 3, the students completed an 18-item physics test (developed by our physics experts as well as our measurement experts). All gameplay and test data were captured in log files. We developed a think-aloud protocol detailing the researcher-initiated prompts on the supports, game features, new tasks and levels, and test items. We also recorded students' additional comments on the game and technical glitches that occurred during gameplay. Such data triangulation allowed for a deep look at what really worked and what did not and gave direction on the next design phase.

We hypothesized that the five supports would be somewhat effective in developing physics understanding (as measured by the physics test). However, the study yielded mixed results—i.e., game tutorials were viewed as generally helpful, and the new manipulation task types were well-received. However, while students clearly favored the worked examples and Hewitt videos, they had mixed (mostly negative) feelings toward the Physics facts and Advice. The data showed that while the worked examples were the most frequently accessed support, the other supports were rarely used. This led us to redesign the learning supports based on five main decisions.

- *Redesign the Support Kit Tab*: None of the students opened the tab voluntarily—we decided to revise the color and position of the tab to make it clear and visually appealing.

- *Revise the Tutorials:* While most students reported the tutorials were straightforward and clear, some had a hard time creating optimal simple machine(s) per level. Consequently, we created and inserted agent-specific tutorials in the support kit tab to remind students to review each when needed.

- *Redesign Physics Facts*: Not surprisingly, the majority of students noted that the Physics facts support was boring. We decided to change the static definitions to a matching game for the terms. In short, they now, interactively, construct their definitions of terms, like a Cloze task (Taylor, 1953).

- *Design Reward System*: Moreover, a number of students mentioned that they would watch the Hewitt Videos, etc. if incentives were provided. This motivated our design of a reward system for the game.

- *Remove Advice*: Students felt that the Advice support was neither specific nor helpful. We decided to remove Advice and design more level-specific physics hints.

After several rounds of discussion and revision, we further refined our supports and came up with the second version of learning supports as shown in Figure 4. The new supports are highlighted in red.

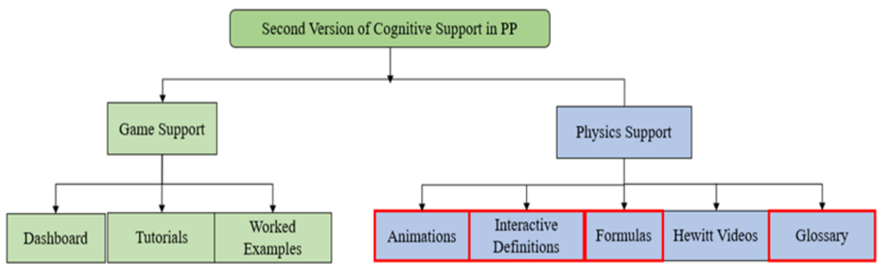


Fig. 4 Second version of supports in *Physics Playground*

In the second version, we made the following changes:

- *New help system*: We regrouped the supports into physics-related and game-related categories. We converted the Physics Facts support to a simpler Glossary. And as mentioned, we added animations, interactive definitions, and formula options to provide additional support for the growth of formal physics knowledge. We also replaced the support kit tab with a simpler Help button. Thus, the new support system provides three types of help: "Show me the Physics," "Show me a Solution or Hint," and "Show me Game Tips" (see Figure 13).

- *Dashboard*: We created a dashboard (Figure 5)—accessible from the main menu in the game— and called it "My Backpack." My Backpack displays the player's progress regarding estimates of current physics knowledge, number of levels completed and remaining, money earned, and a store offering customizable items (i.e., changing ball type and color, changing music, and changing the background image).

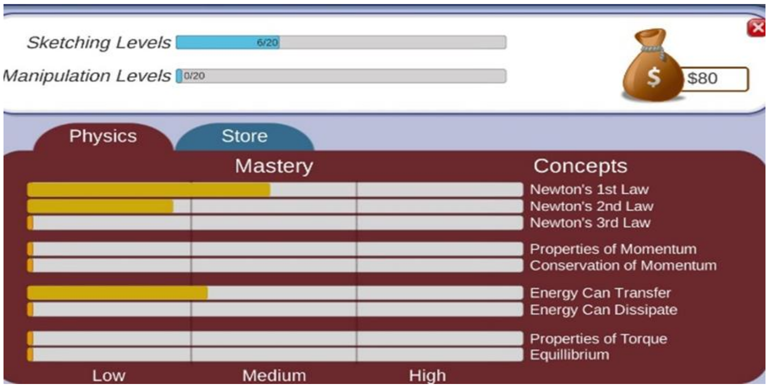


Fig. 5 Dashboard in *Physics Playground* (My Backpack)

- *Reward system:* Research shows that game incentive structures and level progression are core aspects of game rule design (Ke, 2016). The game allows students to earn gold/silver coins when they solve a level or access the supports/game tutorials. The back of both coins shows the head of Sir Isaac Newton. One gold coin = $20, while one silver coin = $10. We employed dollars ($) as the game currency for familiarity. The coins earned will be automatically converted to dollars and appear in the money bag located on the dashboard.

We conducted the second usability study to test the effectiveness of the second version of our learning supports.

4.3 Usability Study 2

In the second usability study, we observed the gameplay of 44 8th grade students at the same school in Usability Study 1 across three days, with a posttest and a questionnaire on day four. The students were assigned to two groups: learning support and non-learning support. Both groups played about 40 minutes each day.

Despite some technical issues, the results showed that students were quite excited and engaged when playing the game. They did note that the tutorials were too long and not interactive, which echoed the comments obtained from the first usability study. Also, like the first usability study, the learning support most accessed by this group accessed was “Show me a Solution” (i.e., worked examples). Again, the other supports were not often used. This reinforced the need for a good reward system operational in the game—to limit the abuse of worked examples, and to direct more attention to the other supports intended to engender physics understanding.

These results motivated us to make the following decisions: (a) revise and operationalize the reward system with a reasonable incentive scheme intended to increase students' motivation to view various physics supports (e.g., we raised the price of a worked example from $30 to $60, changing the cost of a background image from $5 to $20, changing music from $15 to $40, and changing ball color from $30 to $60), (b) add a free hint to the "Show me a Solution" tab, and (c) create interactive tutorials for both sketching and manipulation levels (see Section 4). The current supports are shown in Figure 6.

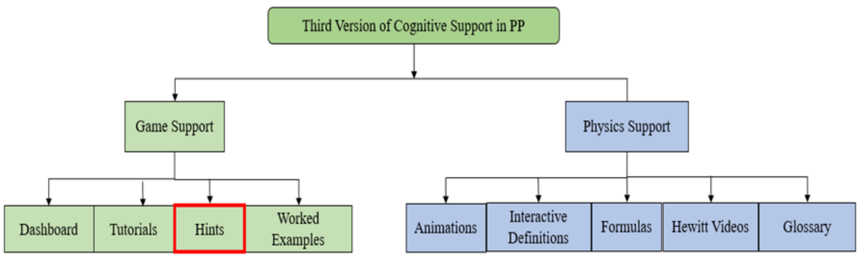


Fig. 6 Third version of supports in *Physics Playground*

4.4 Usability Study 3

Before conducting the third usability study, after looking at what we found from the first two studies, we developed a set of new learning supports, and a new set of test items (i.e., near-transfer items). The purpose of usability study 3 was to (1) investigate the effectiveness of the *new learning supports* accessible via the Help button (i.e., seven animations explaining the energy can transfer [ECT] and properties of torque [POT] concepts with narrations; see Figure 7) when combined with game play, and (2) pilot-test our *near transfer* test items we developed (Figure 8). For these purposes, we selected the two minimally overlapping concepts in our competency model: ECT and POT. We also developed a new set of tutorials for nudge, lever, ramp, pendulum, and springboard. In total, students had 35 levels to complete.

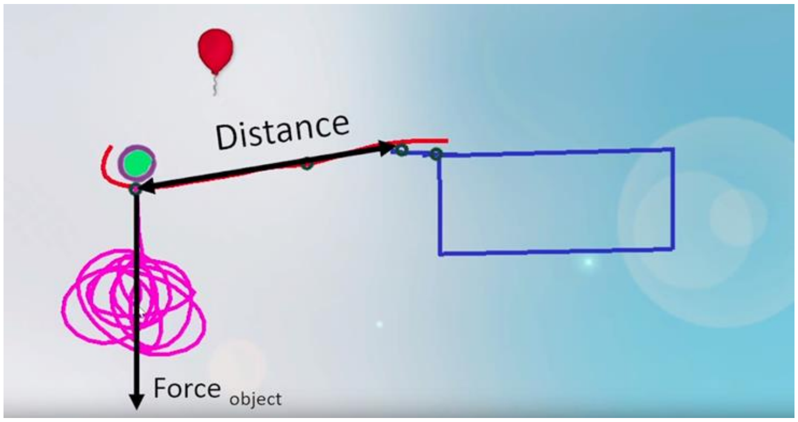
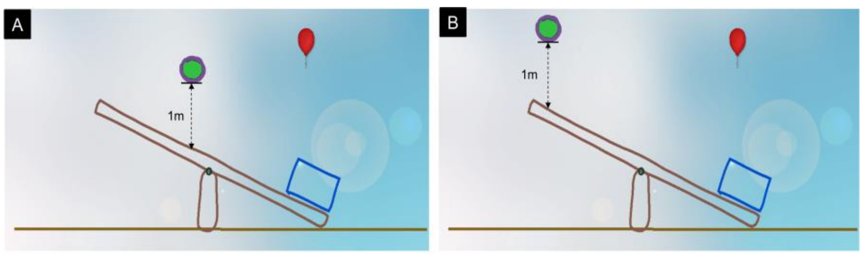


Fig. 7 One of the new learning supports (see the video here).

To evaluate students' physics understanding, we used two physics test forms (Form A = 14 items; Form B = 14 items), each of which included 10 near-transfer test items (i.e., less technical, and more similar to the *PP* levels), and 4 far-transfer test items (i.e., similar to the Force Concept Inventory test items; see Figure 9). Also, to evaluate students' game satisfaction and learning supports satisfaction, we used a 16-item, Likert-scale questionnaire.



In which picture (A or B) will the blue box bounce higher?

a) A
b) B
c) Both will reach the same height.
d) Not enough information

Fig. 8 An example of our POT near-transfer test items. The answer is B.

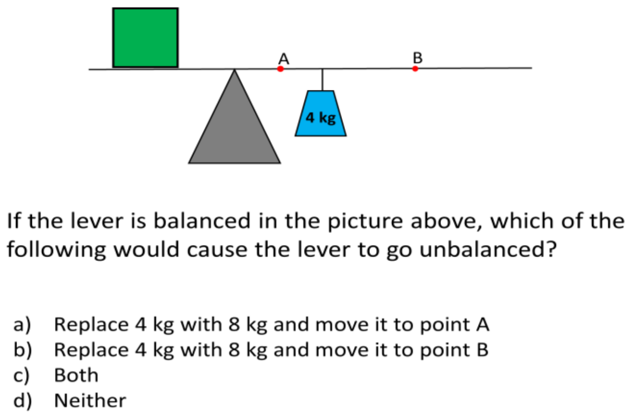


Fig. 9 An example of our POT far-transfer test items. The answer is B.

Our convenience sample included 14 students (6 seventh graders, 8 eighth graders; 6 female, 8 male) from a school of arts and sciences at Florida who were compensated with a $10 gift card upon the completion of the study. Students first completed a demographic questionnaire followed by the pretest in about 20 minutes. Then, all the students played the game for 75 minutes in two stages: (1) the first 20 minutes: getting familiar with the game through the tutorials and freely accessing all the learning supports, and (2) the next 45 minutes: playing the game with accessing only the "physics supports" (in this stage the researchers prompted the students to access the "physics supports" after playing 3 levels or every 8 minutes). At the end of the gameplay, students completed the posttest, and the game and learning supports satisfaction questionnaire (all the tests were administered online using Qualtrics).

Results showed a Cronbach's α of .61 for our ECT and .38 for our POT near-transfer items (both pre and posttest items included; the problematic items have been identified and revised for future use). Students scored significantly higher on the posttest compared to the pretest ($M_{pre} = 0.57$, $M_{post} = 0.63$, $t(13) = -2.20$, $p < 0.05$, Cohen's $d = 0.60$), suggesting learning occurred. Also, the near-transfer pretest significantly correlated with the near-transfer posttest ($r = 0.53$, $p < 0.05$), suggesting reliability.

Finally, the analysis of students' overall game and learning supports satisfaction showed that students really enjoyed playing the game ($M = 4.24$, $SD = 0.62$, where 1 = strongly disagree and 5 = strongly agree), and they saw the learning supports as useful and easy to use ($M = 3.99$, $SD = 0.51$). Moreover, males and females equally enjoyed the game. These findings have convinced us that we are on the right path. We plan to conduct a more rigorous study in the near future to examine the effectiveness of our new supports, and ultimately select the supports that are most effective. Next, we describe the current version of the game.

5. CURRENT VERSION OF PP

As explained in Section 4, over the past two years, we have been designing and testing the effectiveness of a variety of learning supports in *PP* to foster deep, more formal understanding of Newtonian physics. We are finalizing the cognitive supports and working towards developing an adaptive stealth assessment-based level selection algorithm. To get to the current version of the game that was used in our usability studies, we started by establishing a new, broader physics competency model, compared to the sparse model used in the past.

5.1 New Competency Model

Using the Next Generation Science Standards (NGSS) as our guidepost, we worked with our two physics experts to select primary physics competencies and sub-competencies to be assessed in the new version of *PP*. We also identified all salient game behaviors (or "indicators") that can provide evidence of the proficiency status of each variable in the competency model. After many revisions, we finally came up with the competency model shown in Figure 10. The model involves four primary competencies: force and motion, linear momentum, energy, and torque. The model serves as the foundation for subsequent design phases (e.g., designing and developing a new task type).

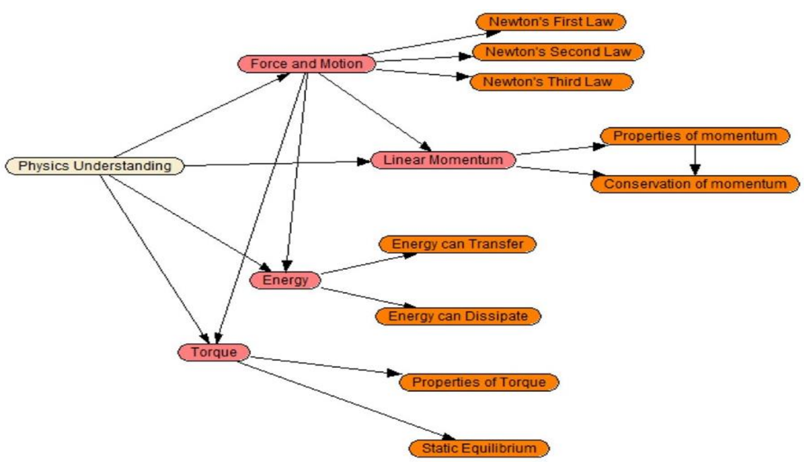


Fig.10 Competency model for Physics Playground

5.2 New Task-Type and Levels

Given this expanded competency model, we needed task types that could elicit evidence of the new physics concepts. This resulted in the design of our new manipulation task type, with drawing functionality disabled. Manipulation tasks require players to adjust three sliders (i.e., gravity, mass, and air resistance), a bounciness option, and add external forces as needed (i.e., static and dynamic blowers, as well as puffers) to solve a level. For instance, solving the *Frog* level (see Figure 11) requires players to adjust air resistance and enable the bounciness function.

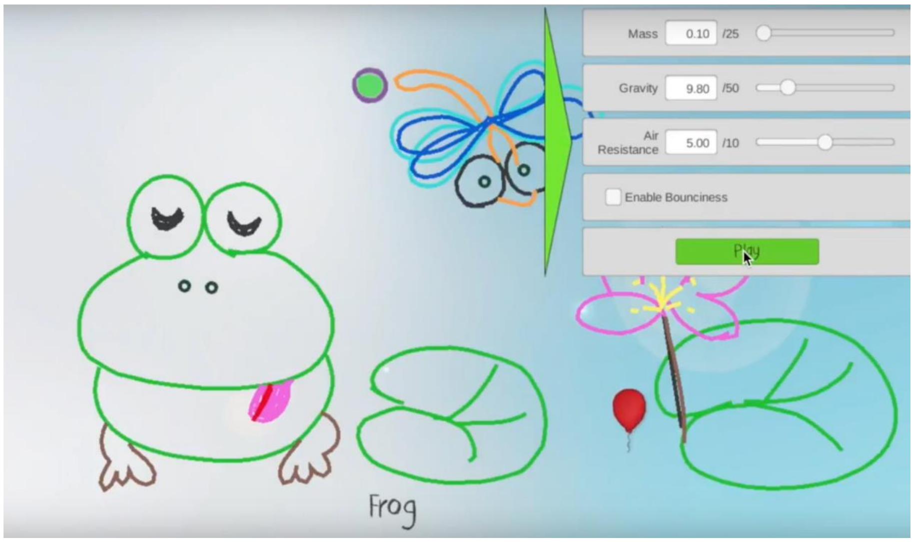


Fig. 11 *Frog* Level in *Physics Playground*

5.3 Specific Learning Supports

Across the past two years, we developed 8 different learning supports for the game: (1) worked examples, (2) animations, (3) interactive definitions, (4) formulas, (5) Hewitt videos, (6) glossary, (7) hints, (8) new physics supports (as we called the new learning supports in Section 3), and (9) interactive tutorials.

In line with Wouters and van Oostendorp's (2013) categorization summarized in Section 2, our worked examples (i.e., short videos showing expert solutions per level) relate to Modeling; our hints relate to Advice; and our animations, formulas, Hewitt videos, and glossary relate to Modality in that each physics concept in the game can be presented across multiple representations of the targeted physics knowledge. We selected Modeling, Modality, and Hints as the main types of support to include in the game because Modeling and Modality appear to be the most effective supports to elevate student learning relative to other learning supports (Wouters & van Oostendorp, 2013).

To access the supports while playing a level, students click the help button (see left panel of Figure 12) in the lower-right corner of the screen (note: currently accessing supports is controlled by the player but in upcoming studies, we will examine the effects of player- vs. game-control of the supports). This triggers a pop-up window showing three options: “Show me the Physics,” “Show me a Solution or a Hint,” and “Show me Game Tips” (see right panel of Figure 12). “Show me the Physics” comprises the main learning support – where students can learn about physics phenomena via multiple representations (i.e., physics animations with narration, interactive definitions, formulas, Hewitt videos, and a glossary). “Show me a Solution or a Hint” and “Show me Game Tips” focus on game-related support – where students can access tutorials, view reminders about game mechanics, and learn about “My Backpack,” the latter depicting their current progress and allowing them to customize the game environment.

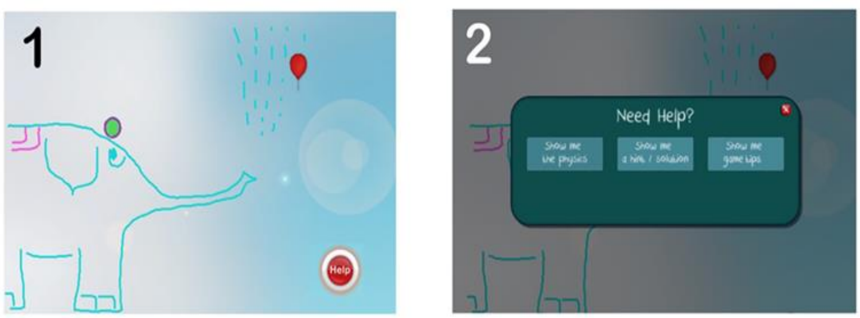


Fig. 12 “Help” button and help menu after the “Help” button is clicked

Show me the Physics leads the student to the physics page showing the following options: “Animation,” “Definition,” “Formula,” “Hewitt video,” and “Glossary” (see Figure 13; note that the formula is not present if the concept doesn’t have an associated formula or equation).

Fig. 13 “*Show me the Physics*” menu

- *Physics animations*. The new physics animations, with narration, connect the physics concepts with how they are applied in the game to solve a level (see Figure 7 for an example). These videos follow the same structure: (1) introduce the concept that will be presented in the video (e.g., “Here you are going to see how energy is transferred to a ball using a pendulum”), (2) state the concept (e.g., “gravitational potential energy is the energy of height…”), (3) demonstrate a failed attempt to solve a level in PP environment (i.e., the pendulum does not have enough angular height), and then (4) show a successful attempt to solve that level.

- *Interactive Definitions*. An interactive task that allows students to drag and drop the choices to the right place and complete a definition of a physics term. In the upper left is the animation related to the term. Students watch the animation and drag the five phrases to the correct blanks within the definition. When the blanks are correctly filled, a congratulation message pops up and students see the complete definition of the term.

- *Formulas*. Not all terms have associated formulas or formulas appropriate for the student level. Clicking on a formula card reveals the formula, along with a short explanation of each component/variable.

- *Hewitt Videos*. Hewitt videos are an engaging series of cartoon videos explaining various physics concepts, developed by Paul Hewitt. The team edited the length of each video to make it illustrate one targeted competency only (we received Paul Hewitt’s permission to edit and use the videos).

- *Glossary*. The glossary provides brief explanations of 28 physics terms. The terms have been selected, edited, and revised by the physics experts.

Each level is linked to only one physics term. However, students can access the glossary at any time.

- Clicking on *Show me a Solution or a Hint* (Figure 13) opens a pop-up window. Based on feedback from two usability studies, we designed hints to help those who are struggling but are reluctant to watch the solutions. For instance, if a sketching level can only be solved by a springboard, the free level-specific hint will be: "Try drawing a springboard." If a student elects to view a worked example, he or she will watch a worked example after paying $60 as a disincentive. All worked examples are 1-2-minute long. The worked examples are complete and can be viewed here on our YouTube channel.

Finally, *Show me Game Tips* (Figure 14) is where students can find game rules, review game tutorial images, and learn about "My Backpack." Clicking on the button leads to a page containing 2-3 tabs. "Controls," "Simple Machines," and "My Backpack" tabs are for sketching tasks, and "Tools" and "My Backpack" are for manipulation.

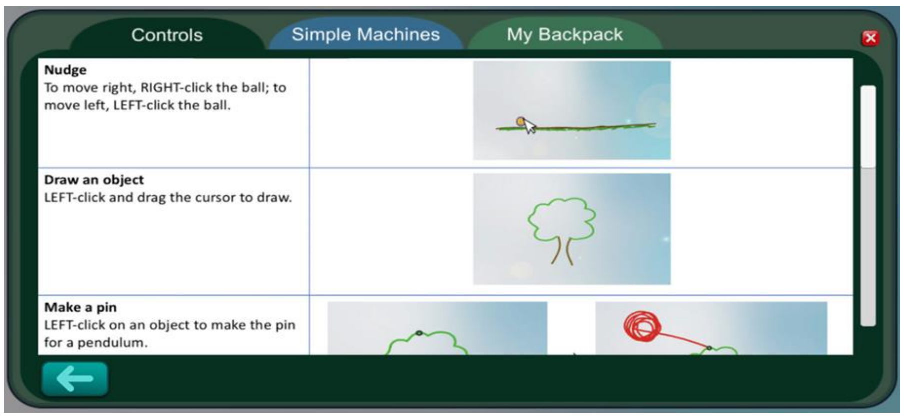


Fig. 14 "*Show me Game Tips*" menu.

- *"Controls" and "Simple Machines."* When a student clicks on the "Controls" tab, a scrollable page pops up showing game mechanics (i.e., nudge, draw an object, and delete an object for a sketching level). When a student clicks on the "Simple Machines" tab, four annotated images of the four simple machines (i.e., lever, pendulum, ramp, and springboard) show up. Each image is clickable and can be enlarged. Viewing the Simple Machines' images the learners can quickly remember how the agents work and they don't have to go through the full tutorials again.

- *Tools*. Clicking on "Show me Game Tips" when the player is in a manipulation level, provides rules for the sliders in manipulation tasks and a short explanation about other tools available (i.e., puffers and blowers).

- *My Backpack*. In both sketching and manipulation levels, "Show me Game Tips" includes "My Backpack." A screenshot from "My Backpack" will be shown with textboxes pointing at different parts of "My Backpack" explaining its function.

- *Game Tutorials*. The tutorials are interactive levels with on-screen instructions. Sketching tutorials show how to draw simple machines. Manipulation tutorials show how to use the puffer/blower (that can exert a one-time and small force or a constant force), sliders (i.e., for mass, gravity, and air resistance), and bounciness function. Students can access them either from the playgrounds or their static images in *"Show me Game Tips"* button.

We will make a decision, based on all the usability study results, about the best learning supports to include in the final version of the game.

6. CONCLUSION AND FUTURE RESEARCH

In this chapter we presented findings related to the effectiveness of educational games, specifically concerning those with embedded learning supports, and discussed various types of learning supports identified in the literature. Additionally, we illustrated how we designed, developed, and tested different learning supports in our educational game—*Physics Playground*. Although the literature is divided about supporting learning in various learning environments (especially exploratory environments), we concluded that having learning supports in educational games can have a positive impact on learning. Among the types of learning supports identified by Wouters and van Oostendorp (2013), reflection, modeling, collaboration, modality, and feedback have been found to consistently enhance learning.

We detailed our efforts in designing and integrating learning supports in the game *Physics Playground*, and determined which supports worked best to foster learning. Our three usability studies yielded mixed results in response to this question, showing that while a large majority of students indeed enjoyed the game, the modeling learning supports (i.e., worked examples) were viewed as the most helpful compared to advice (i.e., hints) and modality (i.e., old animations, formulas, Hewitt videos, and glossary—the multiple representations we developed per relevant physics concept). We also found that our new physics animations are effective and we are currently creating the rest of the videos for all the concepts. Moreover, we found that in the previous versions of the game, students were not adequately motivated to access the other more helpful learning supports (e.g., physics related supports), given the absence of an appropriate in-game reward system. Therefore, we are currently revising the game and supports to (a) further clarify and enhance the appearance and interactivity of the learning supports, (b) provide easier, more direct access to the supports, and (c) set up a compelling and functional reward system.

Moving forward, there are a number of potential avenues for research in this area, such as determining the degree to which a reward system actually influences students' play experience and motivation to access learning supports in the game. Towards that end, we are (1) optimizing the cognitive supports and the game reward system; (2) developing affective supports to complement the cognitive supports that we have developed (not focused on in this chapter); and (3) using stealth assessment technology to serve as the basis for an in-game adaptive algorithm that will select the best next level for a person—one that is not too difficult nor too easy and related to the targeted physics concept.

This sampler of ongoing research will help us and the field figure out ways to optimize the design and delivery of learning supports that may be unobtrusively incorporated into games. The process should be iterative and provide research-backed evidence on: (1) the effects of different types of cognitive and affective supports that promote formal learning and enjoyment in educational games; (2) the timing and control of such supports (e.g., when should they be available, and who—computer or player—controls the delivery; and (3) the factors that mediate the influence of supports on learning and gameplay.

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