International Journal of Game-Based Learning
Volume 12 • Issue 1

Designing and Testing Affective Supports in an Educational Game

Katie Bainbridge, University of Colorado, Boulder, USA
Ginny L. Smith, Florida State University, USA*
https://orcid.org/0000-0002-4415-9123
Valerie J. Shute, Florida State University, USA
Sidney D'Mello, University of Colorado, Boulder, USA

ABSTRACT

Five types of affective supports were designed to induce an appropriate emotional regulation strategy in players of an educational video game. These supports were based on the emotional regulation strategies of situation selection, situation modification, attentional deployment, cognitive change, and response modulation. A series of qualitative studies was designed to answer usability and efficacy questions on the incorporation of these affective supports into the game Physics Playground. Ultimately two of the five support types were removed and the implementation of two others were changed to between game levels rather than in the middle of gameplay. The results also offered insight into the relationship between player ability and when support was preferred.

KEYWORDS

affective support, educational games, emotional regulation in learning, learning games, serious games

INTRODUCTION

Learning and emotion are intimately interwoven (Calvo & D'Mello, 2011; Kim & Pekrun, 2014). Positive affect is found to enhance, and negative affect to inhibit, many aspects of cognition (Clore & Huntsinger, 2007; Fredrickson & Branigan, 2005; Isen, 2008;). This is not universally the case when it comes to complex learning; some negative emotions, such as confusion and frustration, can be beneficial to learning if managed well (D'Mello & Graesser, 2014; Fielder & Beier, 2014). Educational technologies, such as digital learning games, provide a unique opportunity to support students' *emotional* experience while learning (Calvo & D'Mello, 2011). Affective experiences in game-based learning may also influence engagement, a key factor in whether an educational game will have an impact on player learning (Abdul Jabbar & Felicia, 2015). In this paper we discuss the design and formative evaluation of affective supports designed to help players manage their frustration, improve their mood, and increase their motivation to learn in the game *Physics Playground* (Shute et al., 2019).

DOI: 10.4018/IJGBL.304434
*Corresponding Author

DIGITAL LEARNING GAMES AND STUDENT SUPPORT

The ability for digital learning games to increase student learning outcomes through gameplay is well documented in the literature (e.g., Shute, Rahimi et al., 2020; Clark et al., 2016; Mayer, 2019; Vogel, 2006; Wouters et al., 2013), as is the connection between a student's affective state and their learning outcomes (Sabourin & Lester, 2014). A meta-analysis by Clark et al (2016) showed an overall positive effect for supports in learning games; however, the form these supports take can influence how effective they are. Adding supports to digital learning games can have (a) no impact (ter Vrugte et al., 2015), (b) an adverse impact (Adams & Clark, 2014), or (c) a positive impact (Wouters & Van Oostendorp, 2013) on outcomes. In the case of supporting players in digital learning games, design of the supports matters (Shute, Smith et al., 2020; Kuba et al., 2021; Ke, 2016; Wouters & van Oostendorp, 2013).

Previous examples of affective supports in digital learning environments mostly take the form of intelligent tutoring systems (ITSs). Some examples include: Affective AutoTutor, which monitors facial expressions and provides emotional scaffolds in response (D'Mello & Graesser, 2013), (Forbes-Riley & Litman, 2009; Forbes-Riley & Litman, 2011), and an affective learning companion, driven by physiological sensors, that encourages students to use metacognitive strategies in science modeling (VanLehn et al., 2014). These supports all rely upon complicated and/or expensive systems, such as facial recognition or lexical analysis. This research also may not apply to learning games, and the research into affective support in learning games is more limited (Sabourin & Lester, 2014).

A previous study examining the affective states and use of affective regulation strategies of students playing *Physics Playground* found a combination of frustration or confusion and a combination of determination or curiosity were the most prevalent primary affective states reported by students (Spann et al., 2019). Students reported using cognitive reappraisal and acceptance most frequently to regulate their affective state. However the study found that if students reported frustration/confusion, then the use of cognitive reappraisal positively predicted students' gameplay performance along with learning outcomes. However the latter only occurred when students reported high levels of effort. Whereas the use of acceptance was positively related to student outcomes when effort was low and frustration/confusion was high or vice versa (Spann et al., 2019). But when both effort and frustration/confusion were reported as high, the relationship was reversed, decreasing students' learning outcomes (as measured on an external posttest). These results demonstrate that different affective regulation strategies can be beneficial in many scenarios but detrimental in others. The current studies examine students' perceptions and use of a set of embedded affective supports in the game *Physics Playground* to provide insights into how to best support students affective states during gameplay and therefore maximize their engagement, enjoyment, and learning outcomes.

The current studies seek to bridge these gaps by using a qualitative approach to evaluate the impact of multiple affective supports on frustration and motivation in players of a learning game.

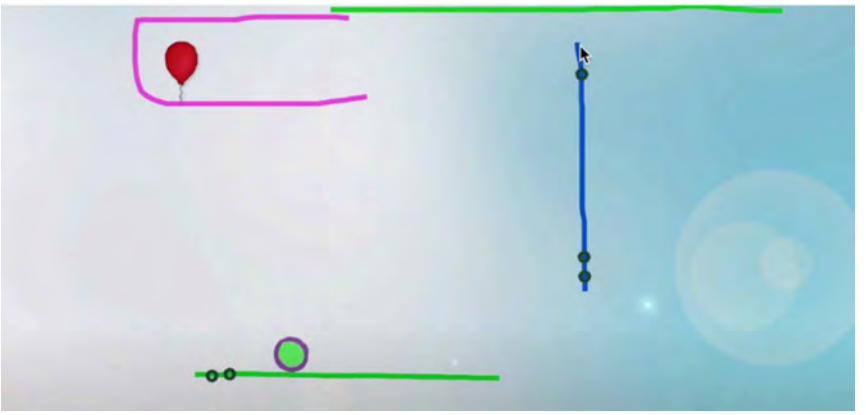
Digital Learning Game

Physics Playground (PP) is a digital learning game designed to teach 7th-12th graders Newtonian physics concepts. Each level requires the player to make the green ball hit the red balloon. Players draw in the environment to create simple machines to move the ball. The first five levels teach the player how to move the ball and how to draw the simple machines used to solve the levels (ramps, levers, pendulums, and springboards). While hundreds of game levels exist, the current study had players play only three levels: *Wavy, Yippie!,* and *Double Hoppy* (see Figure 1), so that all gameplay and interview questions could be completed within an hour.

Support Design

We developed five categories of affective supports fashioned after the emotional regulation strategies outlined by Gross (2008):

Figure 1. A screenshot from the level Double Hoppy



- Situation Modification: Changing aspects of the environment one is in to reduce negative emotions
- Situation Selection: Choosing to be in environments that minimize negative emotions
- Attentional Deployment: Distracting oneself from negative emotions, shifting attention to something else
- Cognitive Change: Reappraising or re-interpreting the situation
- Response Modulation: Suppressing negative emotions

The affective supports were designed to catch a student at a moment of potential negative affect and encourage one or more of the above strategies (see Table 1).

The first affective support condition, Music Change (MC), is triggered if the player remains in a game level for more than 2 minutes. When triggered, the background music of the game will immediately change to a piece of classical music. Three pieces validated to induce positive affect were chosen: 1) Mozart: Eine Kleine Nachtmusik: Rondo; 2) Tchaikovsky: The Nutcracker: Waltz of the Flowers; and 3) Vivaldi, Four Seasons: Autumn I Allegro (Eich et. al., 2007) . This support draws upon situation modification, as an aspect of the game environment has changed, and it also draws upon attentional deployment, as the sudden change may catch players' attention and encourage them to think about something else.

Table 1. Summary of support conditions and the strategies they evoke (Gross, 2008)

Affective Support	Description	Emotional Regulation Strategy(s)
Music Change (MC)	The music switches to a happy song	Situation Modification, Attentional Deployment
Fun Videos (FV)	They player takes a break to watch a fun, physics-related video for about 1 minute	Attentional Deployment, Situation Selection
Motivational Messages (MM)	An encouraging message appears	Cognitive Change, Response Modulation
Calming Center (CC)	The player takes a break to do a breathing, stretching, or guided imagery exercise	Response Modulation, Situation Selection
Secret Store (SS)	The player changes something about the game environment (e.g. the background)	Situation Modification, Attentional Deployment
Cognitive Support (CS)	The player gets a video hint about which machine to use to solve the level	Cognitive Change

In the second affective support condition, Fun Videos (FV), the player is invited to take a break to watch an entertaining YouTube video for about a minute before returning to the game level (see Table 2). A pop-up message would appear as a speech bubble from one of the elements in the game environment (e.g., the balloon) with an invitation to view a YouTube video. Players had the option of clicking the pop-up to start the video or pressing an "X" to close the pop-up and return to the game. This support draws primarily upon attentional deployment, as the purpose is to distract them from their current problem, but it also draws upon situation selection, as it removes them from the game environment temporarily.

Table 2. Description of videos used in Fun Videos support

Video Title	Video Description	Pop-up Message invitation
Isaac Newton vs. Rube Goldberg	A Rube Goldberg apparatus made of household objects.	SURPRISE! Did you know that physics can be used for fun? Click here to see!
8 Easy Physics Tricks to Try at Home	A compilation of DIY instructions to use everyday items to create cool physics effects, e.g., using a AA battery to make a metal coil spin perpetually.	UNLOCKED: Physics tricks to try at home. Click here to watch!
Balloon Rocket	A woman in a lab coat attaches a balloon to a straw around a string, fills the balloon, and lets the air propel the balloon along the string.	CONGRATS! You've unlocked a physics video! Click here to learn how to make a balloon rocket.

In the third support condition, Motivational Messages (MM), the game gives the player an encouraging message if they remain in the unsolved level for more than two minutes. These messages were designed to validate players' frustration and reduce the negative affective consequences of their perceived failure. Three messages were used:

- No one gets this level right away. It's going to take a few more tries to find the solution. Keep going!
- This is a really hard level - you are doing great! Stay at it.
- Did you know that studies show we learn more from failure than from success? Try to build upon what you've learned!

The messages primarily draw upon the cognitive change strategy, encouraging the player to re-evaluate their struggle as a normal part of solving the level. In this way the support also incorporates aspects of response modulation, as this re-appraisal will hopefully reduce the negative affective influence of players' frustration.

In the fourth support condition, Calming Center (CC), the game invites the player to play one of three "minigames": a breathing exercise, desk stretches, or a guided imagery exercise. If the player accepts the invitation, a video player appears and automatically starts playing one of the videos described in Table 3. This

Table 3. Description of videos used in Calming Center support

Activity	Video Description	Pop-up Message
Breathing exercise (Figure 2)	Text instructions tell the player to breathe in and out as a red balloon (using the same art from the game) inflates and deflates. The seconds spent inhaling and exhaling increase by one with each breath until they reach five.	SURPRISE: a breathing minigame! Click here to play
Guided Imagery (Figure 3)	Vivaldi's *Spring*, which is validated to induce positive affect (Eich et. al., 2007), plays over a slideshow of images also validated to induce positive affect (e.g. puppies, natural vistas). Twelve images are shown over the course of 1 minute.	UNLOCKED: the Happy Thoughts sidequest is now available!
Desk Stretches (Figure 4)	A cartoon figure sits at a desk and acts out narrated stretches that can be done while sitting. e.g., "tilt your head forward and roll it to one side, now the other way".	CONGRATS! You've unlocked a bonus game!

Note: The Figures are in Appendix 1.

condition was designed primarily for response modulation, as it uses mindfulness techniques to reduce negative emotions. It also has elements of situation selection, as playing one of the minigames temporarily removes the player from the game environment.

In the fifth support condition, Secret Store (SS), the player is invited to change an aspect of the game: the ball (Figure 5), the background image (Figure 6), or the music (Figure 7) (See Appendix 1 for Figures). Players receive one of three message invitations:

- SURPRISE! You've unlocked the secret store! Try changing the ball color!
- UNLOCKED: The secret store! Try changing the music!
- CONGRATS! You've unlocked the secret store! Try changing the background!

They could then opt to accept the invitation by pressing "OK" or close the invitation by clicking an "X" at the corner of the pop-up message. Changing an aspect of the game employs the emotional regulation strategies of attentional deployment and situation modification; players are taking a break from the level while changing something about the environment.

The sixth support condition is not designed to be an affective support, but a cognitive support. A set of cognitive supports have previously been incorporated into the game, and prior papers have discussed their design (Shute, Smith et al., 2020; Kuba et al., 2021) and efficacy (Shute, Rahimi et al., 2020; Bainbridge et al., 2022). Here we use a type of cognitive support that has been found to be positively correlated to players' learning outcomes as a control condition to establish if any of the five affective supports discussed above are more effective than the cognitive support at reducing frustration or increasing motivation. In this support, players receive an invitation to see a "hint". If they accept, a video player appears over the level environment with an animated physics tip illustrating the simple machine they should use to solve the level. The videos take place in the PP environment, have audio narration summarizing the physics concept, and are less than 1 minute long (see Table 4). The cognitive supports were designed to initiate cognitive change and may be just as effective at reducing frustration and increasing effort as supports designed to target affect. In this sense the cognitive supports served as an active control group, as they have already been incorporated into the game, and a key research question in the current studies is whether they are sufficient in managing player affect or if additional affective supports are still needed.

METHODS

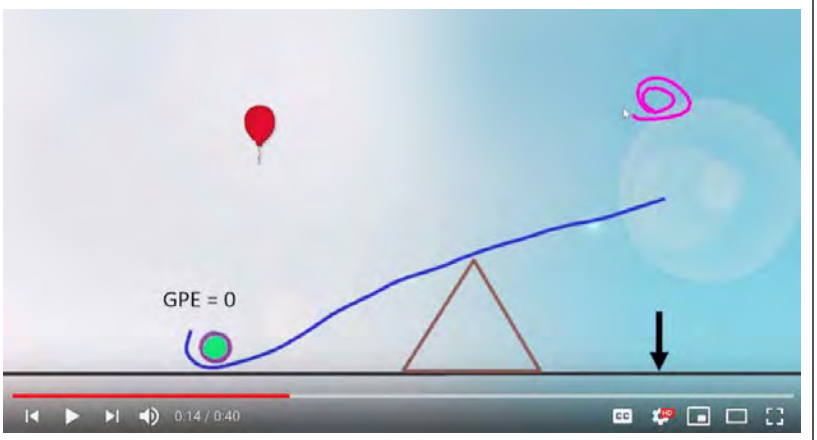
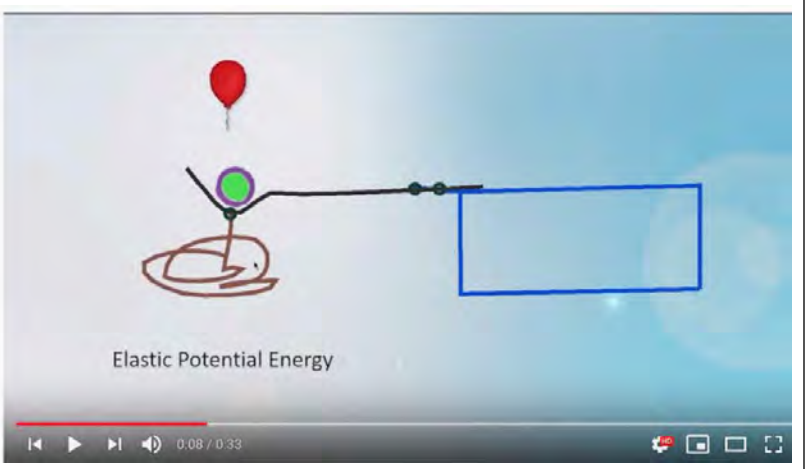
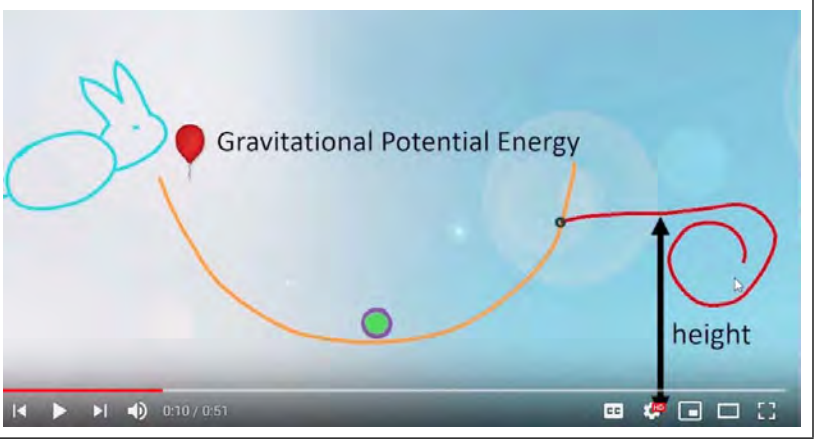
We chose a qualitative approach for this research to address questions a quantitative approach was ill equipped to answer, such as why players chose to engage with some supports and not others, under what circumstances players chose to receive support, what the affective impact of each support was, and if the supports had any unintended effects. A quantitative approach with so many conditions would have required thousands of players, and likely would have missed some of these nuances in the process. We conducted our interviews over the course of 2 studies with different research questions. First, we will discuss the methods and results for the first study.

Supports

All six types of supports were explored in Study 1 and three of the six support conditions were explored further in Study 2. The six support conditions are:

1. Music Change (MC)
2. Fun Videos (FV)
3. Motivational Messages (MM)
4. Calming Center (CC)
5. Secret Store (SS)
6. Cognitive Support (CS)

Table 4. Physics concepts and screenshots of videos used in Cognitive Support condition.

Physics Concept	Video Screenshot
Energy can Transfer-Lever	
Energy can Transfer-Springboard	
Energy can Transfer-Pendulum	

Participants

We recruited two sets of 6 participants between the ages of 18-22 to take part in the two studies through an online ad in a University of Colorado, Boulder campus newsletter. Participants received a $15 Amazon giftcard in exchange for 1 hour of their time during which they played the educational video game *Physics Playground* over Zoom and interviewed.

Procedure for Study 1

In Study 1, players received 3 out of 6 supports on three consecutive levels: *Wavy, Yippie,* and *Double Hoppy*. Who received which support on which level was arranged so that each of the six support conditions were seen three times and each support iteration was seen once over the course of the study.

Table 5 below illustrates that for participant 164 they first received the music change support during the level *Wavy*, then they received the cognitive support during the level *Yippie,* and finally they received the calming center support during the level *Double Hoppy*.

Table 5. Support assignment, Qualitative Study 1

Participant	Wavy	Yippie	Double Hoppy
164	MC	CS	CC
256	FV	SS	CS
345	MM	CC	SS
432	CC	MM	FV
521	SS	FV	MC
613	CS	MC	MM

Players met the researcher in a recorded Zoom video chatroom. First the researcher explained the study and gave them a link to a consent form and demographic survey. After the survey the researcher provided them with a link to the game and their login information. Once in the game the researcher turned off their camera and began recording. The participant played the five tutorial levels without intervention. After the tutorials, they played the level *Wavy*. At some random point between 2-3 minutes after entering the level, the game gave them one of the six supports. After the level, the researcher turned on their camera and asked the participant a set of interview questions. This process was repeated after each level. After the last level and question set, players were asked an additional set of comparison questions that divulged the purpose of the supports, e.g., "Which of the three supports reduced your frustration the most?" After the comparison questions the researcher stopped recording.

Research Questions

Our interviews for this first study were guided by the following research questions: (1) Which supports do players engage with mid-level? (2) Are supports impacting players' moods, and if so, how? (3) Are affective supports helping more/differently in a different way than the cognitive support? (4) Should any support conditions be eliminated?

Interview Questions

Questions Asked After Every Level

After every level, the researcher turned on the camera and asked a series of questions about the support with which they had just engaged.

Questions Asked After All Gameplay

After all three levels had been played the researcher asked the participant to close the game and answer a series of questions comparing all of the supports they received to each other. At this point the researcher disclosed the intended purpose of the supports.

For a list of all interview questions used in Study 1 see Appendix 2.

Quotation Selection

The results sections for both Study 1 and Study 2 contain only a subset of quotations from the players, abridged for space and clarity. An effort was made to have a representative sample of quotations from all players. See Appendix 3 for the tables with selected responses from Study 1. See Appendix 5 for the tables with selected responses from Study 2. In addition, not all the questions asked will be discussed in these results, as some questions were included for aims outside the scope of this paper. For example, responses to "did you feel like quitting" (asked in Study 2) were more relevant to the development of our Quit Model (to be discussed in a future paper), than the evaluation of the affective supports. To see a complete, unabridged list of participant responses to every question, see the supplemental data. Only responses relevant to the research questions for each study will be discussed.

RESULTS FOR STUDY 1

We sought answers to the following research questions while conducting these interviews: RQ1) Which supports are players most likely to engage with during a level? RQ2) Are supports influencing affect, and if so, how? RQ3) Are affective supports helping more/ in a different way than the cognitive support? RQ4) Should any support conditions be eliminated?

RQ1: Which supports do players engage with mid-level?

The supports for the current study were triggered in the middle of a level, randomly between 2-3 minutes after players entered the level. With the exception of the music change support and motivational message support, the supports were opt-in and would temporarily remove the player from the game level. Therefore some supports may not actually be used if presented mid-level. "Engagement" for the MC and MM conditions was defined as whether the player reported noticing the support. "Engagement" for the Fun Video, Calming Center, Secret Store, and Cognitive Support conditions was defined as whether the player opted to leave the game environment to view the support.

Each affective support condition was presented a total of three times across the six players. Table 6 depicts how many players out of those three engaged with each support. Of the supports, the Cognitive Support and Fun Video had the best engagement, with all three players opting to view the respective videos. The Motivational Message and Music Change conditions had the next highest engagement, with 2 out of 3 players reporting they observed the support. Of the 6 support conditions presented, the Secret Store and Calming Center had the least amount of engagement, with 0 players choosing to use these supports.

When asked why they did not choose to use the Calming Center or Secret Store, players cited feeling as though the pop-up message broke their focus and said this type of support would be more welcome if given immediately *after* a level rather than in the middle. One participant said, "I felt like I couldn't visit it because I needed to finish my task first." Another said, "Personally, I felt like the pop-up for the mini game was a bit distracting, as I was midway through the level and I really wanted to finish it. So, for me personally, I probably would have been more incentivized to click on the mini game link if it was given after I just finished the level". As a result of this feedback, we eliminated both the Secret Store and Calming Center as mid-level support options. However, we decided that the supports might still have merit if players used them. We hypothesized that these supports would be more successful if presented between levels as opposed to within a game level. The results of this study will be discussed in a future publication.

Table 6. Support engagement, Study 1

Support	Engagement (out of 3)
Music Change	2
Motivational Message	2
Fun Video	3
Calming Center	0
Secret Store	0
Cognitive Support	3

RQ2: Are the affective supports impacting player affect, and if so, how?

Immediate responses, before the purpose of the supports was revealed, were analyzed by condition to see how participants described the impact of the support on their mood and behavior. The Calming Center and Secret Store supports are not discussed as no players opted to use them. The Cognitive Support condition is discussed in the following section in the context of RQ3.

Music Change

Despite the Music Change support being quite subtle, the two players who noticed the change spontaneously described the music change as reducing their frustration or changing their perspective (see Table 7). This is heartening, as there was a danger that players might not consciously notice the music change, let alone correctly identify its purpose.

Post-game comparison interviews were not as favorable to the music change support. While one person identified it as the most effective at reducing her frustration, the other two players who received the music change support rated it low relative to their other supports. However, this does not seem to be because they disliked the music change, but because it was simply less salient than the other interventions they received. One participant described the music change as their "third favorite" support, rather than their "least favorite". Another said: "the video and motivational message was… more interactive versus like the [music change] was kind of passive. So although I love classical music, I think that would be my third choice". While the music change condition did not fare terribly well in comparison to the other conditions, these responses suggest it was not necessarily less effective or less welcome than the other supports, simply less noticeable. The spontaneous descriptions of the music change reducing participant frustration and changing their perspective prior to the researcher disclosing the purpose of the supports is enough reason to keep this support condition in the running for within-level affective supports.

Fun Videos

Responses to the Fun Videos (see Table 8) suggested that they were generally well liked. Two out of the three players who received the Fun Video support rated it as their favorite. But players also reported confusion, as they expected the Fun Video would help them solve the level (which was not the intended purpose of the support). These findings will be discussed more in depth in RQ4.

Motivational Messages

Overall, the MM condition was well received. One player did not notice the message, and the two players who did notice the support spontaneously described these messages as reducing their frustration and increasing their motivation before the purpose of the supports was disclosed (see Table 9). None of the players disliked the MM they received.

RQ3: Are affective supports helping more/ in a different way than the cognitive support?

Our team had previously spent several years designing, developing, and evaluating cognitive supports for *Physics Playground* (Shute et al., 2020a, 2020b). Because of the careful design and previous positive correlation between cognitive support use and learning outcomes, there was a possibility that the cognitive support would do more to influence player mood than any of the affective supports. To assess this, we had players compare the conditions to each other at the end of their gameplay (See Table 10). Please remember that each player was only shown 3 out of the 6 types of supports, and they are only able to make comparisons among the conditions they were shown.

When asked to pick a favorite support condition overall, two out of the three players shown the cognitive support listed it as their favorite. However, when asked specifically to compare the supports' efficacy in reducing their frustration or increasing their effort, only 1 of the 3 players listed the cognitive support as their preference. This suggests that while cognitive supports are valued, there is some differential value in providing affective supports to address more specific affective states such as frustration. However, as the cognitive support was only seen by 3 out of 6 players, and as some of these players were making comparisons to supports with which they did not engage, these results may be skewed or misleading. For example, player 521 chose the Secret Store condition as his favorite despite not actually using the store during his gameplay. He liked the idea of changing the background and music more than he liked the reality of the supports with which he engaged. Study 2 was designed to follow up on this question more extensively, with all players making comparisons to the same 3 mid-level support conditions throughout the study.

RQ4: Should any support conditions be eliminated?

The final goal of this initial study was to evaluate whether any affective support conditions should be excluded from the game. As discussed in RQ1, both the Secret Store and Calming Center were not used by any player when presented mid-level. Player feedback indicated that this was due to the nature of the support being disruptive to gameplay when presented partway through the level, so it was decided that they should be re-examined as between-level supports rather than be eliminated entirely.

The more surprising and conclusive result of this research question was that the Fun Videos, while being well-received and having high engagement, had unintended consequences for our players. This support was intended to provide a break or distraction to players, rather than a hint. However, because all the Fun Videos were related tangentially to physics in some way, players mistakenly thought the videos were meant to give them insight into how to solve the level. Table 11 is a collection of responses from participants demonstrating the reasonable but incorrect assumption that the Fun Video related to how to solve the level in some way.

One player rated the Fun Videos condition as their least favorite because of this misinterpretation. The video they received depicted a woman in a lab coat making a "balloon rocket" out of a red balloon. Because all game levels have the goal of getting a ball to hit a red balloon, the player made a reasonable assumption that the balloon in the video and the balloon in the level were related, and that the video was telling them they could move the balloon to the ball. Immediately after the video they tested this hypothesis, to no avail, inducing *more* frustration. This suggests that, despite Fun Videos having high engagement and a positive reception overall, the risk of inducing inappropriate schemas through this unrelated content was too great, and the condition should be removed entirely.

DISCUSSION FOR STUDY 1

Our first study had multiple actionable insights. As a result of player responses, the Calming Center and Secret Store were removed from the selection of supports that can be triggered mid-level. These

supports will be revisited in a future study (to be discussed in a separate paper) to see if they still have merit when presented between levels.

Interviews also indicated that the Fun Videos introduced inappropriate schemas in our players, as they naturally looked for a relationship between the content of the video and the level they were trying to solve. This is unsurprising, given the coherence principle of multimedia learning (Moreno & Mayer, 2000), which suggests that the introduction of irrelevant information, particularly if it is interesting, can lead to the learner organizing their mental models around the interesting distractions rather than the relevant content. Despite their warm reception, the risk to learning is too great to continue to include the Fun Videos support.

PROCEDURE FOR STUDY 2

The procedure for Study 2 was almost identical to Study 1, with the exception that all players received the same three supports: MC, MM, or CS (See Table 12). These supports were chosen after data from Study 1 had been analyzed and three support conditions (FV, SS, CC) had been eliminated as options for mid-level affective interventions. Each support was seen on each level twice over the course of the study. As with Study 1, players played five tutorial levels, then the levels Wavy, Yippie, and Double Hoppy. After each level, players were asked the first set of interview questions. After all levels were completed, players were asked the comparison questions. See Appendix 4 for all Study 2 interview questions.

RESULTS FOR STUDY 2

The results from Study 1 were muddled by the fact that participants only saw a subset of support conditions rather than all conditions. This makes it hard to glean meaningful conclusions from questions asking participants to compare the conditions. The purpose of Study 2 was to dig more deeply into the data gleaned from Study 1 and address three key research questions: (1) Are the three remaining mid-level supports effective at reducing frustration, increasing effort, and or improving mood, and is this improvement greater than the cognitive supports already provided? (2) Would players prefer to control if/when they get the supports? (3) When and why should affective supports be triggered? By comparing the same three mid-level supports (Music Change, Motivational Messages, and Cognitive Supports) across all participants, we can more confidently assess their efficacy.

RQ1: Are mid-level supports effective at reducing frustration/ increasing effort/ improving mood relative to the Cognitive Support?

Study 1 provided preliminary insights into this question. Results from that study suggested that while the cognitive support was certainly popular, the Music Change and Motivational Message supports did have differential value to affective states such as frustration. In Study 2, all players saw all three support conditions in a different order, so we can draw stronger conclusions from the comparisons made in this study than in Study 1. We start by discussing the immediate responses to each support condition. Then, we discuss the comparison question results.

Music Change

Three out of the six players reported not noticing the music change. The remaining three players cited feeling more pressure when the music changed, as though the game was drawing attention to how long they'd been playing and encouraging them to hurry up. While this was not an intended effect of the music change, it did seem to inspire these players to try new things or shift their focus. See Table 13 for selected responses.

Motivational Messages

Players responded well to the motivational messages. All six players noticed the message and found them encouraging. All players cited the message as either motivating them to keep trying or inspiring them to try something new. One player doubted they would have completed the level had they not received the Motivational Message. Overall, the message had the desired effects of cognitive change and response modulation in our players. See Table 14 for selected responses.

Cognitive Supports

Multiple players mentioned that the cognitive supports helped them connect the level to the machines and improved how they were applying the machines to the level, which is their intended purpose. This will be discussed more in a later section. While some players said they "knew what to do" after viewing the cognitive support, they did not describe this as increasing their motivation or reducing their frustration until after the purpose of the supports was disclosed. Five out of the six participants found the cognitive supports useful and effective; the remaining participant still found it "helpful", with the caveat that they "didn't really find a solution with it, though". See Table 15 for selected responses.

Comparison Questions

When told the purpose of the supports and asked to compare them across these dimensions, players described the cognitive support as the best at increasing their effort, despite not spontaneously using this language in the prior discussion of the support. The cognitive support was also most frequently reported as players' favorite support, although they slightly favored the motivational messages in terms of frustration reduction.

The Music Change was the least popular condition, with no players selecting it as a favorite in any condition and 5 out of 6 players naming it as their least favorite condition overall. However, when examining their explanations for this ranking, it is clear that music change is not disliked, but simply a less salient "third favorite" for many. This lack of interest in the condition during the comparison phase of the interview suggests the inclusion of this support may not be worth the effort of incorporating it into the game.

Looking more deeply at players' explanations of why and how the various supports were effective at influencing their emotions (see Table 17 for selected responses), it becomes clear that while the Cognitive Support may be listed frequently as a favorite, Motivational Messages have the desired effect on frustration and motivation in most players and should be included in the game.

It is also evident from these comparison responses that the only players who discuss the music change at any length are speaking hypothetically. In addition, these hypothetical situations are not necessarily positive, with one player saying it would be helpful because the music was irritating, and another saying it would be helpful because the change would be "stressful" for some players, with both implying that players would find a solution faster to make the music end sooner. This is decidedly *not* the goal of this affective support, strengthening the implication that we should reconsider its inclusion in the game.

RQ2: Would it have been better for players to control when/ if they got supports?

For Music Change and Motivational Messages, none of the players said that they would have preferred the support if they had been given a choice to engage with it. One player stated, "It would have been inspiring if [the music changing] was something that somehow my actions had prompted. I don't think I would have [voluntarily] been like, 'new music, please'." Likewise, for Motivational Messages one player made the comparison, "It's like when you ask for a cuddle. It's not quite the same as someone opting to give you that". Preference for when and how players received the cognitive support were more varied. The patterns that emerged regarding when players wanted the cognitive support led us to a new hypothesis, which will be discussed in the supplemental analysis later in

the paper. However, for the existing, mid-level, affective supports it seems that adding choice is unnecessary.

RQ3: When and why should affective supports be triggered?

Players generally agreed that they wanted to receive the Motivational Message at a time when they were struggling, and not too soon after starting the level (see Table 18). Where players differed was regarding whether the Cognitive Support should be delivered early in the level or as a last resort. Some players expressed a preference for receiving the CS at the start of the level, to inspire a good strategy right away. One said, "I thought [showing the video in the middle of the level] was just an added complication rather than playing before the game starts or something…[It would have been the most helpful] at the beginning, just because [the video] would have put me on the right lines from the start".

Other players expressed a desire to struggle and find a solution on their own before being offered a hint, preferring the cognitive support to come after they had tried everything else: "I guess it also talked about the actual physics behind it and it showed you the best way to actually tackle it. But I guess I also had less satisfaction of figuring out on my own. So like the [level with the message] I probably had the biggest satisfaction from figuring out on my own."

Interestingly, one player suggested that for easier levels the cognitive support should be given towards the end if the player is struggling, but for harder levels it should be given at the beginning. This insight echoes the individual differences principle of multimedia learning (Mayer & Moreno, 1998), which states that high prior knowledge players and low prior knowledge players will benefit differentially from Cognitive Supports in multimedia learning environments. This player intuitively surmised that if you can predict that a player will struggle on a particular level, it may be better to give the Cognitive Support right away, whereas if a player is displaying a higher level of competence, the Cognitive Support should be given later.

DISCUSSION FOR STUDY 2

Upon looking more closely at just the Music Change, Motivational Message, and Cognitive Supports, it became clear that the Music Change condition was *not* sufficiently impactful to warrant the time and energy necessary to incorporate it into the game. For the Motivational Message condition, we found that players did *not* want to control when they received this support, and that the support would be most effective if delivered at a moment when the player was struggling. Future research should investigate whether previous game behaviors can predict a player's likelihood of quitting or growing frustrated; then the Motivational Message could be delivered at a moment when we know players are struggling.

Timing preference and choice preference were not as clear for the Cognitive Support condition. Some players wanted control over when and if they saw the support, while others preferred to struggle a while before receiving it. This led to a new hypothesis that will be investigated more in the following section.

SUPPLEMENTAL ANALYSIS: HIGH VS LOW MACHINE USERS

In order to better interpret the mixed results we found in regards to the preferred timing of the Cognitive Support, we combined the data from Study 1 and Study 2 and applied an ability level lens. Ability level in this case was operationalized as whether or not the player actually applied the underlying physics content to their gameplay by using appropriate simple machines to solve the levels.

METHODS

Procedure

We developed a scale meant to capture whether a player was likely to use one of the four simple machines (ramp, lever, pendulum, and springboard) illustrated in the tutorial levels to attempt to move the ball. Three coders were trained to distinguish whether a player mostly used machines or mostly just "doodled" on a 4-point "Machine Score" scale. All three coders watched a video recording of each player's gameplay per level and gave them a score of 1-4 according to the scale. We had high inter-rater reliability, with a Cronbach's alpha of 0.89.

Machine scores were then averaged across levels and across raters to form a unified number meant to signify the likelihood that the player would use machines to solve a level. All players who received the cognitive support were ranked by their machine score, and a median split was used to separate "high machine users" from "low machine users". Nine players in total received the Cognitive Supports over the course of the two studies; five of these players were put into the "low machine users" group according to the median split, and 4 of these players were put into the "high machine users" group according to the median split (Machine score = 3.22).

Machine Coding Scale

For each game level played, the player was given a score from 1-4 based on the criteria below.

1. Never draws a machine
2. Mix of machine and doodles and ends without a machine
3. Mix of machine and doodles and ends with a machine
4. Only/mostly draws a machine

A "doodle" was defined as any drawing that was not identifiably one of the four simple machines, or in service of making the machines work (e.g., if a player drew a wedge without using it as a fulcrum, that would be a "doodle", but if a player drew a wedge in order to make a lever, that would *not* be a "doodle").

RESULTS

The purpose of this study was to examine the relationship between game performance and a player's preference for the timing of the cognitive support. We had only one research question: Are players who are engaging with the underlying physics content of the game (i.e., using simple machines to transfer energy) more likely to want the Cognitive Support later than the players who are not successfully connecting the educational content to their gameplay strategy? Selected participant responses are in Table 20 and Table 21 in Appendix 6.

RQ1: Is preference for cognitive support timing related to machine use?

While looking at High and Low machine users as separate groups, a pattern emerged suggesting that the high machine users were more likely to mention machines when describing their thinking, tie what they were doing in the levels to the tutorials, and explicitly relate the terms from the Cognitive Support to their strategy. To further explore this hypothesis, we summed the number of times each player said keywords like lever, pendulum, springboard, ramp, weight, height, and tutorial (see Table 19). Low machine users mentioned the keywords an average of 1.6 times during their interviews, whereas high machine users mentioned the keywords an average of 4.2 times over the course of their interviews. This suggests that our Machine Score metric is successfully capturing the likelihood that

a given player is relating their play to the simple machines that constitute the underlying physics content of the game.

When we separate the players who received the Cognitive Supports in Study 1 and Study 2 into high and low machine-user groups, we can also see a difference between the groups in preference for when and how they wanted to receive the CS. This difference is explored more below.

Low-Machine Users

Low-machine users appear to have a preference for receiving supports early, frequently, and/or on demand (See Table 20). They felt a desire to get help sooner and more often than players who scored as high-machine users.

High-Machine Users

Among the high-machine users, there was a strong preference for receiving the support later (see Table 21). Players in this group wanted the opportunity to struggle before getting an "easy way out" and expressed more satisfaction from solving levels without the Cognitive Support providing them with a hint. Only one player who scored as a high-machine user expressed a desire to get the cognitive support before the level started, in response to the question "When would the support have been most helpful to you?" However, this same player expressed later in the interview that they preferred the Motivational Message support because the cognitive support was a "more blatant answer".

DISCUSSION FOR SUPPLEMENTAL ANALYSIS

In this addendum to our qualitative exploration of affective supports, we combined responses from players in both Study 1 and Study 2 who received the Cognitive Support. Each player was scored on a 4-point scale relative to their "Machine Use", which captured how likely that player was to use a machine to solve a level. This scale had high interrater reliability and was also related to the number of times a user mentioned the machines from the tutorials during the interview (Low $M = 1.6$, High $M = 4.2$).

When preference for the placement of the cognitive support was looked at through this lens, it was clear that low-machine users wanted the support early and often, whereas the high-machine users preferred the support later, after they had had an opportunity to struggle. This is likely related to the Individual Differences principle in multimedia learning (Mayer, 2009)— i.e., the design effects are stronger for low-knowledge than for high-knowledge learners. It is also likely related to the "expertise reversal effect" (Kalyuga, 2007), which suggests that cognitive supports in multimedia learning environments mostly benefit learners with low prior knowledge compared with higher-knowledge learners.

GENERAL DISCUSSION

We used a qualitative approach over the course of three studies to investigate whether the affective supports we had designed were effective and engaging. These supports were meant to reduce player frustration and increase player motivation by introducing emotional regulation strategies (Gross, 2008). For a summary of the supports and the strategies they evoke, see Table 1.

In Study 1 we found that the Secret Store and Calming Center conditions were not used if presented during a level. We also found that the Fun Videos condition violated the coherence principle of multimedia learning (Moreno & Mayer, 2000) and should be eliminated. In Study 2 we eliminated another condition, Music Change, due to its lack of salience. A separate study will investigate whether the Secret Store and Calming Center conditions are effective if presented in a way that encourages higher engagement, such as between levels or using an incentive system (e.g., Rahimi et al., 2021).

Of the remaining supports, Motivational Messages and Cognitive Support, we found that both were effective at reducing frustration and increasing motivation. The Cognitive Support, despite not being

designed to influence affect, was successfully doing so more effectively than other affective supports. The results showed different preferences regarding ideal timing for the two remaining supports. The random triggering of the Motivational Messages, between 2 and 3 minutes after a participant entered the level, was reported to be well timed for most participants across both studies. In the Cognitive Support condition we found that ability level informed when the support was preferred. For participants who were having trouble mapping the gameplay to the underlying physics content, their preference was for the CS to be given at the start of the level. For participants who were successfully using the simple machines that constituted the intended solutions to the levels, their preference was for the CS to be given after they'd had an opportunity to solve the level on their own. Future studies should investigate whether placing the supports earlier or later in the level differentially benefits players of different ability levels with a quantitative approach.

Limitations and Future Directions

The current study, while allowing us to more deeply examine the nuances of how our supports were influencing the players affective experience of the game, relies on qualitative data from a small number of participants ($n = 12$). Future studies should confirm that these affective supports have a positive impact on learning by using a mixed-methods approach, incorporating quantitative measures of learning gains in physics knowledge into the analysis.

While our manual "Machine Score" code seemed to be accurately capturing the likelihood a player would use machines to solve levels, it was only feasible to do so because we had a limited sample size and few levels. It would not be feasible to apply this method to quantitative interventions, which involve hundreds of players playing dozens of levels. In the hopes that a less labor-intensive version of the score could be created, we compared our manual machine scores to a machine score generated by an algorithm using gameplay behaviors collected in log file data. That is, the game automatically labels and stores each action a player takes, including if they have drawn a ramp, lever, pendulum, or springboard. We used the number of levers, pendulums and springboards divided by the number of machines drawn in total to create an automatic machine score. Ramps were excluded from this score because the game will categorize most straight lines as ramps, even if they are not used that way. Our manual machine score and this automatic machine score were significantly correlated ($r = 0.72$, $p = 0.03$), indicating that we can use the automatic machine score in larger studies going forward to explore the relationship between machine use and learning.

The difference in preference for support placement between low and high-machine users suggests that future studies should explore whether adaptive placement of cognitive supports based on machine use and other measures of attainment of educational content can benefit both populations. For example, if the game could automatically detect how often players are using machines to solve levels, it could use that metric to shift the placement of the CS to better meet the players' needs.

CONCLUSION

A series of qualitative interviews proved an efficient way to evaluate a large number of affective supports designed to reduce frustration and boost motivation in an educational game. Using feedback from 12 players helped us to narrow six categories of affective supports down to two that have the desired impact on players when triggered in the middle of gameplay: Motivational Messages and Cognitive Supports. The rich feedback gained in this series of studies has set up future explorations of placing supports between levels as well as the potential use of "machine score" to predict support placement preference.

The current study adds to the body of literature by proposing a cost- and time- effective way of narrowing down a wide range of possible methods of influencing player affect. This qualitative data focuses future quantitative study designs that can more effectively find a link between player affect

and learning outcomes without being underpowered, and gives insight into *why, when* and *how* the supports are influencing affect.

CONFLICT OF INTEREST

The authors of this publication declare there is no conflict of interest.

FUNDING AGENCY

This research was supported by the US Department of Education (IES #039019) and the US National Science Foundation (NSF #037988).

REFERENCES

Abdul Jabbar, A. I., & Felicia, P. (2015). Gameplay engagement and learning in game-based learning: A systematic review. *Review of Educational Research*, *85*(4), 740–779.

Adams, D. M., & Clark, D. B. (2014). Integrating self-explanation functionality into a complex game environment: Keeping gaming in motion. *Computers & Education*, *73*, 149–159.

Bainbridge, K., Shute, V., Rahimi, S., Liu, Z., Slater, S., Baker, R. S., & D'Mello, S. K. (2022). Does embedding learning supports enhance transfer during game-based learning? *Learning and Instruction*, *77*, 1–11.

Calvo, R. A., & D'Mello, S. K. (Eds.). (2011). *New perspectives on affect and learning technologies* (Vol. 3). Springer Science & Business Media.

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research*, *86*(1), 79–122.

Clore, G. L., & Huntsinger, J. R. (2007). How emotions inform judgment and regulate thought. *Trends in Cognitive Sciences*, *11*(9), 393–399.

D'mello, S., & Graesser, A. (2013). AutoTutor and affective AutoTutor: Learning by talking with cognitively and emotionally intelligent computers that talk back. *ACM Transactions on Interactive Intelligent Systems*, *2*(4), 1–39.

D'Mello, S. K., & Graesser, A. C. (2014). Confusion. In *International handbook of emotions in education* (pp. 299–320). Routledge.

Eich, E., Ng, J. T., Macaulay, D. P. A. D., Percy, A. D., & Grebneva, I. (2007). Combining music with thought to change mood. Handbook of emotion elicitation and assessment, 124-136.

Fiedler, K., & Beier, S. (2014). Affect and cognitive processes in educational contexts. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), International handbook of emotions in education (pp. 36–55). Routledge/Taylor & Francis Group.

Forbes-Riley, K., & Litman, D. (2011). Benefits and challenges of real-time uncertainty detection and adaptation in a spoken dialogue computer tutor. *Speech Communication*, *53*(9-10), 1115–1136.

Forbes-Riley, K., & Litman, D. J. (2009). Adapting to Student Uncertainty Improves Tutoring Dialogues. In V. Dimitrova, R. Mizoguchi, B. du Boulay, & A. Graesser (Eds.), Artificial intelligence in education (pp. 33–40). Academic Press.

Fredrickson, B. L., & Branigan, C. (2005). Positive emotions broaden the scope of attention and thought-action repertoires. *Cognition and Emotion*, *19*(3), 313–332.

Gross, J. J. (2008). Emotion regulation. Handbook of Emotions, 3(3), 497-513.

Isen, A. M. (2008). Some ways in which positive affect influences decision making and problem solving. Handbook of Emotions, 3, 548-573.

Kalyuga, S. (2007). Expertise reversal effect and its implications for learner-tailored instruction. *Educational Psychology Review*, *19*(4), 509–539.

Ke, F. (2016). Designing and integrating purposeful learning in game play: A systematic review. *Educational Technology Research and Development*, *64*(2).

Kim, C., & Pekrun, R. (2014). Emotions and motivation in learning and performance. Handbook of research on educational communications and technology, 65-75.

Kuba, R., Rahimi, S., Smith, G., Shute, V., & Dai, C. P. (2021). Using the first principles of instruction and multimedia learning principles to design and develop in-game learning support videos. *Educational Technology Research and Development*, *69*(2), 1201–1220.

Mayer, R. E. (2009). *Multimedia learning* (2nd ed.). Cambridge University Press.

Mayer, R. E. (2019). Computer Games in Education. *Annual Review of Psychology*, *70*, 531–549.

Mayer, R. E., & Moreno, R. (1998). A cognitive theory of multimedia learning: Implications for design principles. *Journal of Educational Psychology*, *91*(2), 358–368.

Moreno, R., & Mayer, R. E. (2000). A learner-centered approach to multimedia explanations: Deriving instructional design principles from cognitive theory. *Interactive Multimedia Electronic Journal of Computer-Enhanced Learning, 2*(2), 12-20.

Rahimi, S., Shute, V., Kuba, R., Dai, C. P., Yang, X., Smith, G., & Fernández, C. A. (2021). The use and effects of incentive systems on learning and performance in educational games. *Computers & Education*, *165*, 104135.

Sabourin, J. L., & Lester, J. C. (2014). Affect and engagement in Game-Based Learning environments. *IEEE Transactions on Affective Computing*, *5*(1), 45–56.

Shute, V., Almond, R., & Rahimi, S. (2019). *Physics Playground (1.3)* [Computer software]. https://pluto.coe.fsu.edu/ppteam/pp-links/

Shute, V. J., Rahimi, S., Smith, G., Ke, F., Almond, R., Dai, C.-P., Kamikabeya, R., Liu, Z., Yang, X., & Sun, C. (2020). Maximizing learning without sacrificing the fun: Stealth assessment, adaptivity, and learning supports in educational games. *Journal of Computer Assisted Learning*, 127–141. doi:10.1111/jcal.12473

Shute, V. J., Smith, G., Kamikabeya, R., Dai, C.-P., Rahimi, S., Liu, Z., & Almond, R. G. (2020). The design, development, and testing of learning supports for the Physics Playground game. *International Journal of Artificial Intelligence in Education*. Advance online publication. doi:10.1007/s40593-020-00196-1

Spann, C. A., Shute, V. J., Rahimi, S., & D'Mello, S. K. (2019). The productive role of cognitive reappraisal in regulating frustration during game-based learning. *Computers in Human Behavior*, *100*, 358–369. https://doi-org.proxy.lib.fsu.edu/10.1016/j.chb.2019.03.002

VanLehn, K., Burleson, W., Girard, S., Chavez-Echeagaray, M. E., Gonzalez-Sanchez, J., Hidalgo-Pontet, Y., & Zhang, L. (2014). The affective meta-tutoring project: Lessons learned. *International Conference on Intelligent Tutoring Systems*, 84-93.

Vogel, J. J., Vogel, D. S., Cannon-Bowers, J., Bowers, C. A., Muse, K., & Wright, M. (2006). Computer gaming and interactive simulations for learning: A meta-analysis. *Journal of Educational Computing Research*, *34*(3), 229–243.

Wouters, P., van Nimwegen, C., van Oostendorp, H., & van Der Spek, E. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology*, *105*(2), 249–265.

Wouters, P., & Van Oostendorp, H. (2013). A meta-analytic review of the role of instructional support in game-based learning. *Computers & Education*, *60*, 412–425.

APPENDIX 1

Figure 2. A screenshot for the Calming Center support "Breathing Exercise"

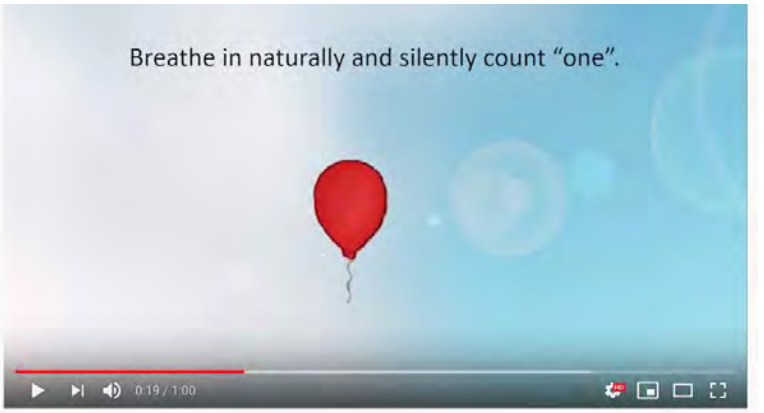


Figure 3. A screenshot of the Calming Center support "Guided Imagery"

Figure 4. A screenshot of the Calming Center support "Desk Stretches"

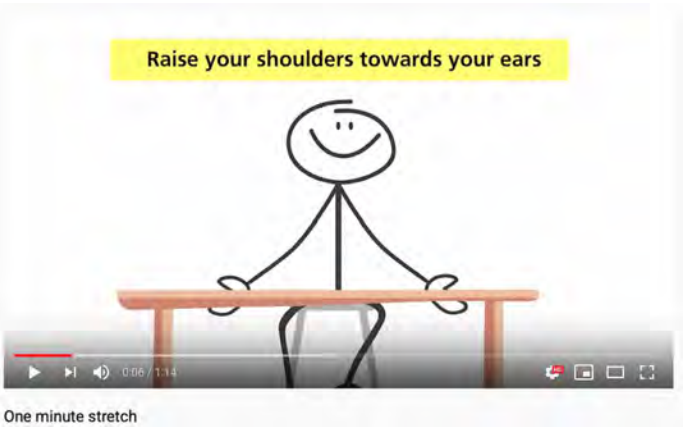


Figure 5. The Secret Store support inviting players to change the ball

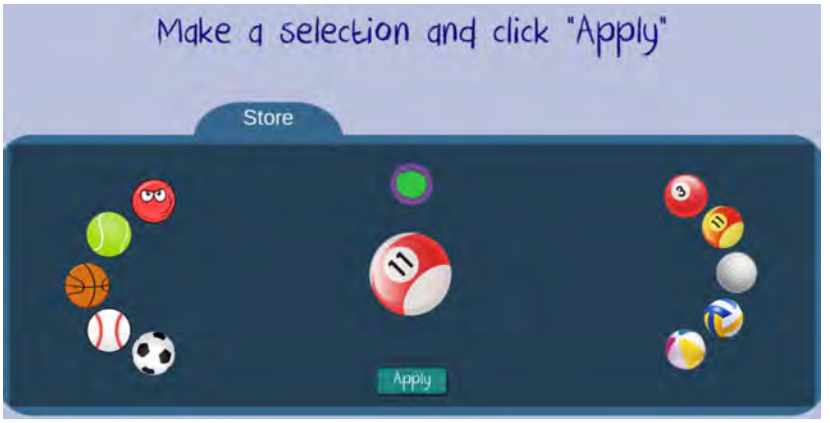


Figure 6. The Secret Store support inviting players to change the background image

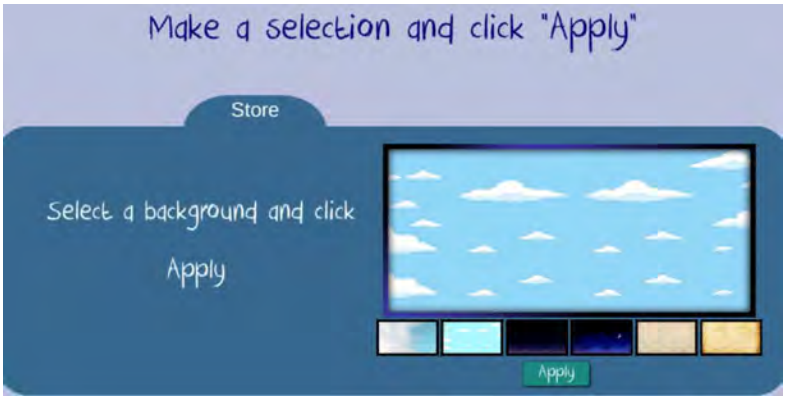
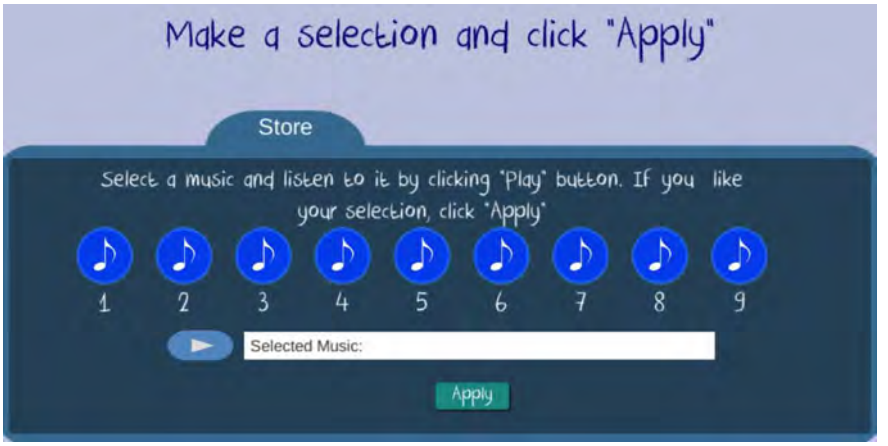


Figure 7. The Secret Store support inviting players to change the music



APPENDIX 2

Interview Questions Study 1

Questions asked after each level	
1	Did you notice the [support]?
2	What do you think was the purpose of the [support]?
3	Just before the [support] came up, what were you thinking and feeling?
4	When the [support] came up, what did you think and feel?
5	What did you think about the [support] while you were [engaging with it]?
6	When you came back to the [level], after [the support] what were you thinking and feeling?
6a	Did your gameplay change?
6b	Did you feel any different than you did before the [support]? (If struggling): Did you feel any better or worse?
7	When would the [support] have been most helpful to you?
7a	(if struggling to answer): did it come at a good time, or would you have preferred it earlier or later in the level? why?
Questions asked after all gameplay	
1	Between the [support 1], [support 2], and [support 3], which did you like best? Why?
2	Between the [support 1], [support 2], and [support 3], which did you like least? Why?
3	The [support 1, support 2, and support 3] that came up partway through the levels are called "supports". One of the goals of these supports was to help you feel less frustrated while playing the game.
3a	Did the supports reduce your frustration? Why or why not?
3b	Which of the 3 supports you saw reduced your frustration the most? Why?
3c	What would you change about the supports to make them more effective at reducing frustration? You can talk about specific supports or more generally.
3d	How would you design a support to reduce frustration? What would it look like and how would it work?
4	Another goal of these supports was to encourage you to keep trying when you might otherwise have quit or felt discouraged.
4a	Did the supports make you want to keep trying? Why or why not?
4b	Which of the 3 supports you received increased your desire to keep trying the most? Why?
4c	What would you change about the supports to make them more effective at maintaining/increasing effort? You can talk about specific supports or more generally.
4d	How would you design a support to maintain/increase effort? What would it look like and how would it work?

APPENDIX 3

Table 7. Selected responses to questions regarding the Music Change support, Study 1

Question	Quote
Did you feel any different than you did before the music changed?	Slightly, but in like a positive direction. I didn't have like a very significant difference, but then like slightly in a positive, or less frustrated
Did your gameplay change?	I didn't notice anything different about my playing, if it changed
	I guess like I changed my perspective, because I was trying to do it one way and then the music changed. And I was like, oh wait maybe I could do it a different way, like a pendulum. And then that ended up working. So I guess it did like help me
What did you think about the music change while you heard it?	Cool music, but it was distracting, so I didn't like having music
What do you think was the purpose of the music change?	Maybe to get my brain thinking in a different way, a different mindset
	I guess if it was faster. It would make you like more urgent at your task. Or just to maybe get a reaction out of the user to see like if they would realize, oh, I might have been stuck on this for a while to, like, notice that the song had changed so…
	OK, so my first thought was, maybe like to help because I know that a lot of my friends listen to classical music when they study. So maybe it'll help like me focus more, um, that's like subconsciously, that's my first guess. And then my second thought is that maybe if students get…bored of the original music, you might need to change it up… or give me a new thought process like maybe the music will generate new ideas
When the music changed, what did you think and feel?	Actually, probably still frustrated, a little bit, not much different
	Oh, it was actually a good distraction, like I was just like, kind of getting stuck. But then the music changed. I was like, okay, refresh, refresh my brain and then just like try to think again

Table 8. Selected responses to questions regarding Fun Videos, Study 1

Question	Quote
What did you think about the video while you were watching it?	I was just like, well, this is so cool. I was very interested in like watching closely because I couldn't quite-Like my mind couldn't quite figure out what was going on… I was trying to, like, look for something that would give me a hint as to what was going on in the video
	I was just kind of not seeing the correlation between the level and the video
What do you think was the purpose of the video?	The idea was to kind of encourage me to look at something from a different perspective or, you know, be willing to try new things and not, not just like focus on something, one specific facet of the problem, but maybe try a bunch of different things
	I guess to show the like the propulsion, you need to like launch the ball. Um, I don't know, I guess it kind of confused me because to me, when the video popped up, it made me think that I was able to use the balloon to somehow complete the level well
When the video came up, what did you think and feel?	I was interested. I was like, Okay, cool. Let's see what this is about
	I thought that the video was kind of similar to like those little five minute videos you see come up on Facebook, all the time, which I thought was pretty interesting, I think, it was entertaining and helped give me some ideas for what to do with the level going forward
	I felt happy because I thought I was going to get help from the game to finish the level
When you came back to [level], after the video what were you thinking and feeling?	Um largely the same as I did previously. I think I would have felt better if there was like an actual tip to help solve the level.
	I guess I just felt confused. Like I said, because I thought the balloon was going to help me finish the level.
Did you feel any different than you did before the video?	Probably better just because it was a, it was a bit of a break
	I felt slightly more motivated because they're just more ideas that came up. Ah, on my end, personally, um, I guess that's pretty much it.
	Confused
Did your gameplay change?	I don't know if my gameplay changed… I got a little less frustrated because my mind kind of took a break from the problem I was trying to solve. So it was just like nice to have something to focus on other than the problem and then come back to it after

Table 9. Selected responses to questions regarding Motivational Messages, Study 1

Question	Quote
What did you think about the message while you were reading it?	I think the content in the message was helpful and encouraging, but it wasn't a tip that directly contributed to help me solve the level
	I was like aw, the game [is] so supportive. I thought it was really sweet. [It gave me] a boost of confidence
What do you think was the purpose of the message?	To provide encouragement, when I wasn't yet close to solving the level or I was struggling
	Oh, to encourage students because if this is a higher difficulty, they might want to give up during the middle of it
When you came back to the [level], after the message what were you thinking and feeling?	It gave me more motivation, because, um, it said that it was like a harder level than the previous ones that I was like, I need to finish this one
Did you feel any different than you did before the message?	Um, so it just gave me motivation. But then it was just like it took away like frustration I guess if there. I didn't have too much frustration, but if I did, then it would have I think
Did your gameplay change after the message?	I was trying to like calculate all my steps and then make sure that everything was perfectly set up, but then this one I just kept drawing until like it worked like, I think that made it made it like active [i.e., permission to try anything]
Why was it your least favorite?	Because I feel like it while it was encouraging, didn't really provide any tangible solutions to help me solve the level
Why was it your favorite?	I haven't really done many psychological studies, but I'm seeing that was kind of a nice reminder that like this is not a trick. This isn't like a, you know, this is like this is something that you can do. It's not like an impossible task

Table 10. *Participants' responses when comparing supports they received in Study 1.*

Player	Favorite	Least favorite	Best at reducing frustration	Best at increasing effort
164	Cognitive	Secret Store	Cognitive	Cognitive
256	Fun Video	NA	Fun video	Fun video
345	Motivational Message	Calming Center and Secret Store	NA	Motivational Message
432	Fun Video	Motivational Message	Fun Video	Fun video
521	Secret Store (hypothetically- did not notice)	Fun Video	Secret Store (hypothetically)	Secret Store (hypothetically)
613	Cognitive	Music Change	Music Change	Motivational Message

APPENDIX 4

Interview Questions Study 2

Questions asked after each level	
1	Did you feel like quitting at any point during the level? When and why?
2	Did you notice the [support]?
3	What do you think was the purpose of the support?
4	Please describe your thoughts, feelings, and gameplay as they developed from just before the [support] came up, as you [engaged with the support], and after.
4a	Did you notice a change in your thoughts, feelings, or gameplay?
5	When would the [support] have been most helpful to you?
5a	(if struggling to answer): did it come at a good time, or would you have preferred it earlier or later in the level? why?
6	Would you have liked [the support] more if you had *chosen* to get it?
Questions asked after all gameplay	
1	Between the [support 1], [support 2], and [support 3], which did you like best? Why?
2	Between the [support 1], [support 2], and [support 3], which did you like least? Why?
3	The [support 1, support 2, and support 3] that came up partway through the levels are called "supports". One of the goals of these supports was to help you feel less frustrated while playing the game.
3a	Did the supports reduce your frustration? Why or why not?
3b	Which of the 3 supports you saw reduced your frustration the most? Why?
3c	What other kinds of messages would have reduced your frustration? Think of as many as you can.
3d	What other kinds of song changes would have reduced your frustration? Think of as many as you can
4	Another goal of these supports was to encourage you to keep trying when you might otherwise have quit or felt discouraged.
4a	Did the supports make you want to keep trying? Why or why not?
4b	Which of the 3 supports you received increased your desire to keep trying the most? Why?
4c	What other kinds of messages would have increased your effort? Think of as many as you can.
4d	What other kinds of song changes would have increased your effort? Think of as many as you can.
5	What Combination would work best for you? Under what circumstances would you want each type of support?

APPENDIX 5

Table 11. Responses from Fun Videos condition that demonstrate support-induced misconceptions

User	Quote
Did your gameplay change?	I did try like some things that I thought were interesting such as like this spiral technique in the video at one point
What did you think about the video while you were watching it?	Um, I try to incorporate some of the techniques I saw in the video, but none of them ended up being successful. But I did try like some things that I thought were interesting
	I was just kind of not seeing the correlation between the level and the video
What do you think was the purpose of the video?	To provide inspiration for ways I could solve the level
	I guess to show the like the propulsion, you need to like launch the ball. Um, I don't know, I guess it kind of confused me because to me, when the video popped up. It made me think that I was able to use the balloon to somehow complete the level well
When the video came up, what did you think and feel?	I think, it was entertaining and helped give me some ideas for what to do with the level going forward
When you came back to the level after the video what were you thinking and feeling?	I guess I just felt confused. Like I said, because I thought the balloon was going to help me finish the level.
Why was it your least favorite?	Just because I thought that it didn't really help me progress the level it just kind of gave me a physics tip that I didn't think was relevant to it. Had it been more like correlated to the level [I would have found it more] beneficial.

Table 12. Support assignment, Study 2

Participant	Wavy	Yippie	Double Hoppy
136	MC	MM	CS
361	MM	CS	MC
631	CS	MM	MC
316	MM	MC	CS
163	MC	CS	MM
613	CS	MC	MM

Table 13. Selected responses to questions regarding Music Change, Study 2

Question	Quotation
Did you notice a change in your thoughts, feelings, or gameplay after the music changed?	And then when it did change, it felt like there was more like pressure. So I was trying to be better at trying different things, which I don't think I actually did but it felt like I needed to
	I think once the music started going, I kind of felt like the way I had was gonna work. It's kind of going a little faster between each try, trying to get it to work.
What do you think the purpose of the support was?	A first it stressed me out. So I was like, f*ck, I should have finished it already. But I hadn't. So it's like okay I guess it's nice that it's not the same [kind of music].
	It kind of got more I guess, energetic to like to get you, has lots of swinging and the sound and get you more. To keep trying and yeah classical
	Um, I don't know, maybe like to show like how long it's taking maybe, like the longer you take like the more like music changes there are?

Table 14. Selected responses to questions regarding Motivational Messages, Study 2

Question	Quotation
Did you notice a change in your thoughts, feelings, or gameplay?	Once the message came up, then I was like, okay, cool on the right track... and then eventually I came up with the good idea
	I don't think it [the message] affected me that much. It kind of did give me inspiration I guess in different ways to solve it
	I felt more relaxed, knowing that I wasn't the only one who struggled with it. I'd say that kind of gave me a chance to sort of take five and think of different solutions. I felt more relaxed about it and just, you know, it didn't matter that I wasn't able to get it up
	And then it popped up and then so I was like, I guess I can try a different method and it's going to be more difficult than I thought it was going to be. And then once I did that, I tried the new method and that worked.
	I think so. I don't think I would have [won], like I was literally just redoing the exact same thing over and over before it came up
Please describe your thoughts, feelings, and gameplay as they developed from just before the message came up, as you read the message, and after.	I was [still using] trial and error... And then I saw the message at like the point of feeling like there's no way I could figure this out. But then I saw the message. It definitely made me feel a little bit better.
	Yeah. I mean, I think I was just repeating the exact same actions over and over, and then I got the message. And I tried something different. And that didn't go well. So I went back to the same thing, but made like alterations on the same like action. But just like slightly different
What did you think of the message?	It definitely [helped] because I think it had said that I'm like on the right track. So that made me feel better and made me want to keep going. So I was like, if I'm on the right track, that I should keep goin' and I'll get it eventually. So definitely encouraged me to keep going.
What do you think the purpose of the message was?	Um, so like since like you're failing it like gives you inspiration to like keep on trying to succeed
	To encourage me to not give up and keep trying
	So because I was just doing the same method and it wasn't working. And so when it said that kind of gave me the confidence that it's gonna be hard. I just got try different ways.
	Well, once it said that I was like okay I should try something different, because clearly what I'm doing isn't working. But then I tried something different. And that was worse. So like, okay, it must be asking me to learn from like, what I did was close but not quite there.

Table 15. Selected responses to questions regarding Cognitive Supports, Study 2

Question	Quotation
Did you notice a change in your thoughts, feelings, or gameplay?	And then after watching the video I tried to use [a] spring to get the energy
	Then I saw the video and it said to actually attach something and use it as like a diving board. Using the weight to pull it down to then when I actually did it I attached it and used the weight and then once it pulled it down I then released it using the energy.
	After the video, I understood how to use the shape that I had and I was able to use trial and error to know what to do.
Please describe your thoughts, feelings, and gameplay as they developed from just before the [support] game up, as you [engaged with the support], and after.	At first I was just trying to click the ball, but then I remembered the tutorials and tried drawing the lever and points, but it wasn't in the right places. Then after the video, I understood how to use the shape that I had and I was able to use trial and error to know what to do.
	Yeah, I mean, I think I was just kind of trying things. I think I made a pendulum, perhaps, I don't know, and so then when I saw the video had used like, a lever I think. Oh, well I was like, Oh, I'm not solving it the way I'm supposed to but I think very close to the way I was doing. So I feel like it showed a different probably simpler way to solve it

Table 16. Favorite condition comparisons, Study 2

Condition	Favorite*	Least Favorite	Best at Reducing Frustration	Best at Increasing Effort
Music Change	0	5	0	0
Motivational Message	2	0	4	2
Cognitive Support	5	1	3	5

*Out of 6; some categories sum to 7 if a player named two favorites.

Table 17. Selected responses to questions regarding Comparing supports, Study 2

Question	Quotation
Did the supports make you want to keep trying? Why or why not?	Yeah, because just like you know there was a solution to the problem, and they just kind of like encourage you to just like keep looking for it. [A reminder that there is a solution]
	Uh, yeah, I think the [message]. It made me kept trying because I knew it should be difficult. [Cognitive support] made me wanna keep trying, because it gave me a good sense of what I needed to do to solve the problem with a different method that I could try, the [music change] was probably the least effective want me to keep trying, because there's a very slight change just to the music, which something I might not notice.
	Not the music. But the other two [CS and MM]. Yeah.
Did the supports reduce your frustration? Why or why not?	I think they did. Again, it's hard with the music because I didn't notice it, but I mean, maybe I like subconsciously noticed it, but the hint in the encouraging message really did help made me want to not quit and to, you know, have guidance or just have somebody say like on the right track. Keep it going, you know. So I do think that they helped a lot.
	And the [motivational message] definitely did reduce my frustration, just because of that I felt like I wasn't alone and that just to hang in there.
	Yeah, for example, the [message]. When I was feeling a little frustrated. I said, Oh, it's gonna be difficult. Most people struggle and then gave me the feeling that I'm not alone in this. It should. I should be struggling and then with, like the hint. It provided like me how to actually figure it out. And then the music was like uplifting.
	I think the message definitely reduced it a little bit. I think it kind of validated my frustration.
	And I don't think the music did mostly because I'm pretty good at like tuning it out, and since it had been the same music the whole time I just like didn't notice it was there so I wasn't stressing me out. But I think if I'm thinking of something like the Jeopardy song were like that could have been stressful for someone. It would be nice but not for me. But yeah, I think the message and the video were both supportive like the message made me feel like I wasn't doing everything wrong so that I would get there eventually. And the video was more like you maybe you're doing things wrong. But here's a different way to do it, which was also useful
Which of the 3 supports you received increased your desire to keep trying the most? Why?	Probably the video. Because, like I got the concept like I knew kind of what concept. Like the video was showing. I was just trying to figure out like how to make it fit with the problem.
	The [message] did, and to be fair, I mean, the video did make me keep trying, because it like because it gave me a guidance of how it might work that may be keep going, you know, that was like knowing there was a solution. [For the music, a hypothetical] Yeah, maybe, maybe reduce my frustration, just because it doesn't become so irritating as time goes on and annoying.
Which of the 3 supports you saw reduced your frustration the most? Why?	Um, going to say probably be encouraging message, just because I was just a little like what else can I do here, and having that there was like okay, I just need like one more object or something and then I can get it going, just like think a little harder and you'll be able to get it kind of thing. So it's a probably that one so it's nice to get some praise
	And the [message] definitely did reduce my frustration, just because of that I felt like I wasn't alone and that just to hang in there.
	Probably the [CS], because it basically relieved the frustration immediately because it gave me how to do it.
	I think the message definitely reduced it a little bit. I think it kind of validated my frustration.

Table 18. Selected responses to questions regarding support timing preference, Study 2

Question	Quote
Is there a way you would want to combine the supports over the course of the levels? If so, how?	"I feel like all three like fit like work very well. If, like if the [message] and the video were like spread out like the [message] would go like first and then like some time goes by and then like the video, I feel that would've been the best"
	"I definitely think I could see all three going together and like one level... maybe like in the middle you'd have the message pop up. But then like a little bit afterwards. You'd be like, Here's a hint. Since you seem to be struggling and that would be there so I think"
	"Yeah, I could see them all been played together. I think the video might be good up front so that you kind of start off in the right direction. And then obviously as time goes on. Maybe the message of encouragement and music changes sort throughout to see you don't get kind of bogged down with it"
	"Yeah, I think you could possibly use all three like the hand if there was like an optional thing that you can click and then the music. You could just have start on those right away and then the [message], you could have that be a little bit farther along so you have different stages of help, that can keep you being less frustrated and then as a last resort, you can do the hint"
What Combination would work best for you? Under what circumstances would you want each type of support?	"I mean, if I imagine them like in succession. I feel like it would be nice to get the message first and then if you still can't figure it out then to have the video. And to me, the music change feels like the very last, like, you're so close, and you're getting there. So that would have to like come last in my mind"
	"Going off of that assumption that like the video kind of gives you the most keys to open the door. I feel like the message would be better before that, because I don't think there would have been very useful like it like what the video first and then the message last because I mean, maybe I guess for the harder challenges... maybe having them the video and then the message on the like the harder tasks"
When would the support have been most helpful to you?	"I think that timing [of the message] was good because I was like failing. So I guess it was like a good way to add the message"
	"I think [the message] did come at a good time. So at that point, like in the middle ish. I was like, okay, nothing's working. I don't know what else I can do. And then the message popped up. And it was like, 'you're on the right track.'"
	"I think [the video] was pretty helpful right when I needed it. I think if it's too early. It would require no thinking on my end. And then too late. You're already ready to like give up."
	"I think [the message] came at a good time. I think too early and it would have lost its effect by the end. I've got frustrated probably towards the end. So I think it was quite good timing really"
	"At the beginning, just because [the video] would have put me on the right lines from the start"
	"I think [the video] could have come slightly later. I feel like the hint…should be your last resort"
	"I mean I guess that would depend on what you're looking for, because at the beginning, [the video] would have been helpful to give me like a gauge of like what I'm supposed to be doing. But if you're trying to like make me think really hard about it, then I guess where it was good"
	[Regarding the cognitive support] "I mean, probably in the beginning before I even started the task"

APPENDIX 6

Table 19. Machine use and CS timing preference

High/Low	Participant	Machine Score	CS Timing Preference	# of mentions
Low Machine Scores	316	1.67	Earlier	2
	136	2.78	No change	2
	256	2.89	On-demand	1
	631	3.11	Earlier	3
	164	3.22	On-demand	0
High Machine Scores	361	3.33	Later	3
	611	3.33	Earlier	8
	613	3.33	Later, except on difficult levels	3
	163	3.78	Later	3

Table 20. Selected responses from Low Machine Users, Bonus Study

Question	Quote
How would you design a support to maintain/increase effort?	"I would... make [the video] optional the watch or not. And then I would make it available to click at the bottom"
What would you change about the supports to make them more effective at reducing frustration?	"I think a hint on every level would be helpful support."
When would the cognitive support video have been most helpful to you?	"I think the video might be good up front so that you kind of start off in the right direction."
	"I mean I guess that would depend on what you're looking for, because at the beginning, it would have been helpful to give me like a gauge of like what I'm supposed to be doing. But if you're trying to like make me think really hard about it, then I guess where it was was good"
Why didn't you like the cognitive support video?	"Just because I thought [the video in the middle] was just an added complication rather than playing [the video] before the game starts or something."
Would you have liked the cognitive support more if you had chosen to get it?	"Probably. I mean, I guess if it was at the beginning, I would have just appreciated it being there. But if it were to come up at some point throughout the game. I would rather have chosen when."

Table 21. Selected responses from High Machine Users, Bonus StudyS

Question	Quote
Is there a way you would want to combine the supports over the course of the levels? If so, how?	"maybe like in the middle-ish you'd have the message pop up. But then like a little bit afterwards you'd be like, 'Here's a hint. Since you seem to be struggling'"
	"Yeah, I think you could possibly use all three... as a last resort, you can do the hint."
What combination would work best for you? Under what circumstances would you want each type of support?	"Going off of that assumption that the video kind of gives you the most keys to open the door. I feel like the message would be better before that... maybe I guess for the harder challenges, the video, given that the video might not give you everything you need.... so maybe giving them the video and then the message on the like the harder tasks"
When would the support have been most helpful to you?	"I think it was pretty helpful right when I needed it. I think if it's too early it would require no thinking on my end."
	"I think it could have come slightly later. I feel like the hint.. should be your last resort… So quite a little later."
	"I mean, probably in the beginning before I even started the task."
Which of the 3 supports you received increased your desire to keep trying the most? Why?	"Definitely the [message]… because the video, it was really helpful, but then it was kind of giving you the steps to complete it. It was a more blatant answer, I guess, compared to the [message], where it's like, encouraging you. Explaining that we know this is hard… that was more helpful personally"
Why [wasn't the CS your favorite]?	"I don't want to be like almost given the answer, because then that's not as great."
	"Because [the video] talked about the actual physics behind it and it showed you the best way to actually tackle it. But I guess I also had less satisfaction of figuring out on my own. So like the [level with the message] I probably had the biggest satisfaction from figuring out on my own."
Would you have liked the support more if you had chosen to get it?	"I'm gonna say, probably not just because I feel like that's an easy way out. So I kind of like it when it was more we'll choose to give it to you instead of me choosing to get it because then like that requires no thinking on my end, if I constantly have a hint, ready to go."
Would you have liked the support more if you had chosen to get it?	"I don't know if I would have liked the video more. I think I never would have used it earlier... I think I could have liked relied on it maybe too much. Um, but I think I don't think I would have liked it more like the content of the video or like the way it was presented... [without the video] I'll be able to just try to think more in that headspace of being creative and using like the things I already know how to do to accomplish the task, if that makes sense."

Ginny Smith is an educator, designer, and researcher with a Ph.D. in Instructional Systems and Learning Technologies from Florida State University. Her research centers around the design, development and evaluation of learning games and interactive learning experiences for STEM learning in secondary and higher education.

Val Shute is the Mack & Effie Campbell Tyner Endowed Professor in Education in the Department of Educational Psychology and Learning Systems at Florida State University. Her current research involves using games with stealth assessment to support learning—of cognitive and non-cognitive knowledge, skills, and dispositions. Her research has resulted in numerous grants, journal articles, books, chapters in edited books, a patent, and a couple of recent books.