Supporting Social-Emotional Development in Collaborative Inquiry Games for K-3 Science Learning

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Abstract: While games for science learning show considerable promise, they tend not to focus on the youngest students. We are engaged in a project to create and evaluate a series of games for science learning for students in Kindergarten through grade 3. These games address a range of educational goals: to help students understand targeted science principles, develop scientific inquiry skill, and deal with situations that call for social-emotional skill. In two of our games, *Beanstalk* and *Teeter Totter Go,* players alternate between problem-solving activities and inquiry activities integrated in a single narrative context. The main contribution of the work is a design for science games for young children that synergistically addresses scientific inquiry, social-emotional development, and science content learning. The games serve as platforms for research into how best to support this synergy.

Introduction

Although recent reviews concluded that there is little scientific evidence that educational games can effectively support science learning (Honey & Hilton, 2011; Tobias & Fletcher, 2011; Young et al., 2012), the landscape is beginning to change. There are by now quite a few games for science learning and evidence is beginning to emerge that they can be effective (Barab et al., 2009; Ketelhut, Nelson, Clarke, & Dede, 2010; Meluso, Zheng, Spires, & Lester, 2012). However, relatively few science games exist for young children at the beginning of their school careers (e.g., Kindergarten through grade 3). Designing effective games for this age group is a significant challenge, even beyond the usual challenges involved in designing educational games.

While scientific inquiry is widely viewed as an important educational objective (Honey & Hilton, 2011), it is a great challenge for a young demographic to learn these skills. It is appropriate to focus on supporting inquiry skills as a *collaborative* activity for a number of reasons. First, “real” scientific inquiry is almost invariably a collaborative process. Further, collaborative learning, appropriately scaffolded, has a strong track record in improving learning (Kollar, Fischer, & Hesse, 2006). Finally, learning to collaborate well is an important goal in its own right. However, collaborating is not easy for children in this age group as they may not have fundamental collaboration skills or the necessary social and emotional maturity. Therefore, to support collaboration and children’s ability to collaborate, our work focuses on measuring and scaffolding students’ social and emotional learning (SEL). Differences in socio-emotional skills—such as individual persistence and healthy interdependence—can be predictive of later academic success (Cunha & Heckman, 2006). An additional goal in our games is for students to come to a better understanding of the physical phenomena that they are investigating through collaborative inquiry. We focus on physical systems and principles that are rich enough to provide a real challenge and sense of discovery, but are not so complicated (in terms of physics and mathematics) as to be beyond the age group’s ability to comprehend.

Underlying our games is a fundamental design hypothesis yet to be confirmed, namely, that these combined objectives are achieved when inquiry activities are interleaved with problem-solving activities within a single narrative context, and opportunities for SEL (such as seeking help and acknowledging and resolving different viewpoints) are embedded in a way that is relevant to the on-going inquiry and problem-solving activities. This narrative context provides motivation, meaning, and a degree of cognitive structure (e.g., Dickey, 2006). We see many open questions related to how best to achieve this combination. We view our games as platforms to investigate these questions. At this stage, the games offer initial approaches, not final answers.

In this paper, we present two of our games, *Beanstalk* and *Teeter Totter Go (*http://www.etc.cmu.edu/engage/*).* We discuss the three educational objectives addressed in these games and illustrate how these games address those objectives.

Educational objectives

As part of our approach to creating effective educational games (Aleven, Myers, Easterday, & Ogan, 2010), we spent a significant amount of time identifying the objectives that the games address.

Scientific Inquiry learning objectives

Scientific inquiry requires a broad range of skills and methods, but what subset of these skills is within reach of children in grades K-3? Guided by the National Research Council Framework (National Research Council, 2012), we decided to focus on making predictions as well as arguing from evidence. Specifically, the games aim to help students learn to:

1. make predictions about how the given physical system will behave in a specific case;
2. observe whether predictions are met;
3. explain observations by identifying features of the physical system that caused the outcome;
4. pose hypotheses as to how features connect to outcomes, recognizing that there are sometimes competing hypotheses;
5. recognize whether an observation is consistent with, inconsistent with, or not relevant to a given hypotheses; and
6. revise a hypothesis as necessary in light of observations.

These objectives are consistent with the NRC standards: #3) Planning and carrying out investigations, #4) Analyzing and interpreting data and #6) Constructing explanations and designing solutions consistent with available evidence.

Science content learning objectives

In addition to objectives for learning inquiry, *Beanstalk* and *Teeter Totter Go* are designed to support science content learning. The goal is for students to understand the principles governing the balance scale and the sum of cross products rule (weight x distance from fulcrum) that can be used to determine when a scale will balance. For instance, if the blue supports are removed from under the balance scales in Figure 1, in both instances the left side will go down. Prior research and our own preliminary data indicate that understanding the balance scale poses a substantial challenge for children in the targeted age group. Our games are designed to help children progress through a series of four increasingly sophisticated mental models first described by Siegler (1976):

Figure 1: Balance scale problems

1. Children only pay attention to weight, not to how far away from the fulcrum the weights are; children with this mental model make incorrect predictions for both cases in Figure 1.
2. Children also consider distance, but only when the weight is equal on both sides; otherwise, they go by weight. Children with this mental model correctly predict the case on the left in Figure 1 but not the one on the right.
3. Children consider both weight and distance, but when these two cues suggest different outcomes (i.e., one side has more weight, but the weight on the other side is further away from the fulcrum), they do not know how to resolve the conflict and guess. Children with this mental model recognize that the scale shown on the right in Figure 1 is problematic but do not know how to deal with it.
4. Children use the sum of cross products rule. Only children with this level 4 model are able to solve all balance scale problems correctly.

Social-Emotional Learning Objectives

A key challenge for 21st-century schools is serving culturally diverse students with different abilities and motivations for learning. Programs geared toward social and emotional learning have been shown to increase academic performance, to improve attitudes about self and others, and to promote positive social behaviors within schools (Durlak, Weissberg, Dymnicki, Taylor, & Schellinger, 2011; Payton et al., 2008; Zins, Weissberg, Wang, & Walberg, 2004). For our age group, state standards for social and emotional/personal development typically focus on self-concept, self-regulation, and the development of social interactions. Kindergarten educators focus on pro-social relationships with peers and adults. By second grade, there is an additional focus on caring for others and on self-reliance. Throughout this period, socio-emotional learning principles concentrate on a healthy balance between independence and interdependence, between pride in one's own work and recognition of the value of others' work, between becoming self-reliant and learning to ask for help.

To support this social development goal of positive interdependence, the games are designed to create scenarios around three SEL goals, namely, that children learn to:

1. ask for help when encountering a problem,
2. cooperate with a peer to reach a shared goal, and
3. solve disagreements through interactions and discussions with peers.

The Games: *Beanstalk* and *Teeter Totter Go*

A key challenge in the design of our games is to tie together the three categories of educational objectives in a coherent and game-like manner. As mentioned, each of *Beanstalk* and *Teeter Totter Go* uses a single narrative context to guide players in problem-solving tasks and inquiry tasks, each related to the same physical system (i.e., the balance scale). The knowledge gained through these two types of activities may be mutually reinforcing. Problem-solving activities pose engaging challenges and may enhance a student's intuitive understanding of physics. On the other hand, inquiry activities may help students develop scientific reasoning skills and help them develop a more verbal understanding of the given physical system– for example, explanations and hypotheses as to when the scale balances or tips.

Figure 2: *Beanstalk* problem-solving level (left) and inquiry level (right)

Beanstalk is based on the folktale of *Jack and the Beanstalk,* in which Jack climbs a beanstalk that grows into a land where an evil giants lives. In the *Beanstalk* game*,* the evil giant is replaced by a friendly monster living on the moon. While asleep, the monster unknowingly pushes his teddy bear out of bed causing it to fall all the way down to earth, landing right where Jack and Jackie live. The player must return the monster's teddy bear. Luckily, a large beanstalk has sprouted, offering a way to where the monster lives, but it will not grow if the beam at the top does not stay balanced. Unfortunately, the beam attracts bugs, causing it to tilt (Figure 2, left). Thus Jack or Jackie must continuously balance the beam by growing flowers to counterbalance the bugs (see Figure 2, left). Balancing the beam in increasingly more challenging configurations is the main problem-solving activity. These activities are interleaved with inquiry activities. Occasionally, a flock of seagulls lands on the beam, blocking progress. They will not "skedaddle" until the player carries out an inquiry as to whether the beam will balance and why (see Figure 2, right). With the seagulls departed, the beanstalk continues to grow as long as the player keeps the beam balanced. Eventually, the player returns the teddy bear for a happy reunion with the friendly monster.

In *Teeter Totter Go* problem solving and inquiry activities are embedded in an overall narrative. *Teeter Totter Go* is an adventure set in an outback wilderness area. The player, a young ranger (see Figure 3), must deliver badges for a new cohort of young rangers to a remote ranger station. Unfortunately, a villain runs off with the badges and, while fleeing, looses the badges scattering them across the wilderness. The player must follow the villain's path to collect the scattered badges. Along the way, she must cross ravines by walking over a log that teeter-totters on a big rock. To walk over the log, it must first be moved into the right position, either horizontal or tipped to the left or right (Figure 3, left). The player moves rocks on or off the log while collaborating with Billy, a non-player character (NPC) sporting a purple jersey. The player then walks across the log, collecting badges as she goes.

Figure 3: *Teeter Totter Go* problem-solving level (left) and inquiry level (right)

Problem-solving activities in which the goal is to balance or tip the log are interleaved with inquiry activities in which the player poses hypotheses about balancing. The inquiry activities commence immediately following a cut scene in which the villain expresses confidence that the player will *never* be able to figure out how to find all the badges. The player can prove the villain wrong by figuring out, through inquiry, a general principle for making the log balance or tip (figure 3, right). The villain gloats if the player's explanation was incorrect or expresses dismay that the player was able to "figure it out." Eventually, the player delivers the badges to the ranger station.

Problem-Solving Levels and How SEL is Supported

In both games, the problem-solving levels are sequenced from easy to hard based on the Siegler models described above. Although the two games have different level sequences, in both games, the early levels target situations in which both the weight and the distance (i.e., how far away the weight is from the fulcrum) is kept the same on both sides of the beam or log (Siegler level 1). On these levels, a simple "mirroring" strategy suffices to balance the beam or log. On subsequent levels, the mirroring strategy does not work, either because there is not enough weight to put on the beam or log, or because positions needed for mirroring are blocked. (Positions on the beam or log may be blocked from receiving weights in order to prevent solutions that are either simpler or harder than intended.) These levels are more challenging as players learn to trade off weigh versus distance, applying simple versions of the cross product rule (Siegler level 4). Several additional factors are varied to affect the difficulty of levels, such as the number of "weights" available, the number of positions in which there are weights, and the positions on the beam that are open or blocked

As mentioned, a key aim in designing the games was to support players' social and emotional development, with a focus on help seeking, collaboration, and resolving disagreement through discussion. As we sought to support these goals in *Beanstalk* and *Teeter Totter Go,* several design issues came under consideration. It was important to emulate social interactions, but we could not allow children to chat or speak directly with each other, as a privacy and security concern for parents, given that the games were designed for use on the Internet, not just in schools. As a result, our games rely on interactions through game objects and menu options. Likewise, due to the technical challenge of connecting two or more players for the same game session, we decided to focus our first iteration on individual gameplay situations in which the player collaborates with one or more NPCs.

We first consider interactions with NPCs that occur on the problem-solving levels. In the *Beanstalk* game, the player interacts with two characters, Chicken and Crow, with different personalities and capabilities to support socio-emotional learning. To support our first SEL goal, help seeking, at any time, the player can click on the buttons for Chicken or Crow to ask for help (Figure 4, left, bottom). Both characters are forthcoming with useful advice as to how to balance the beam but also mix in other commentary. At the higher tiers, *Beanstalk* also supports collaboration, our second SEL goal. The player can leverage Chicken and Crow's special abilities. When the player runs out of water and therefore cannot grow any more flowers to balance the beam, he or she can ask Chicken to lay eggs and thus add weight to the beam (Figure 4, left, top-right). Likewise, at the player's request, Crow will eat bugs, which cannot be removed otherwise, to reduce the weight on the other side of the beam.

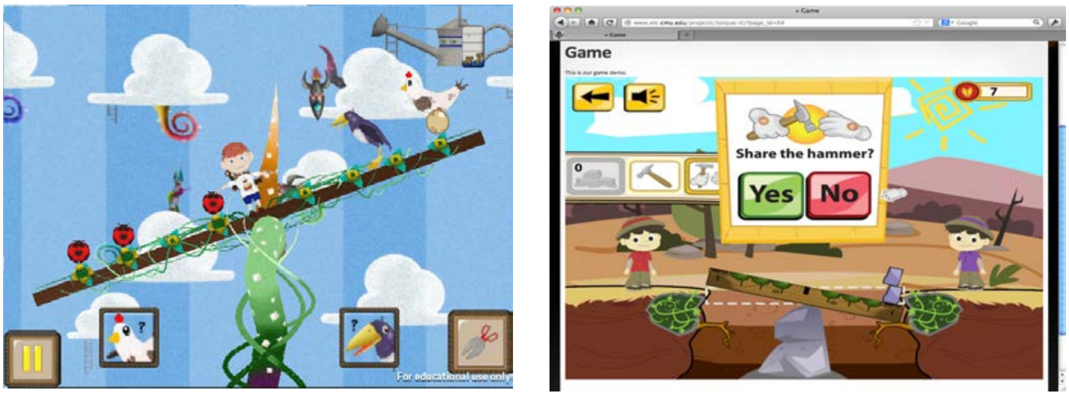

Figure 4: SEL support during problem solving in *Beanstalk* (left) and *Teeter Totter Go* (right)

In *Teeter Totter Go*, as in *Beanstalk,* the SEL support on the problem-solving levels focuses on help seeking and collaboration. The player collaborates with an NPC (Billy) at the opposite side of the ravine. They take turns adding or removing rocks, working on their own end. When the log reaches the correct position and the player walks across to join the peer, both characters smile. Thus, a key incentive for defeating levels is a social one. Moreover, some levels require sharing of resources: the player or Billy must use a hammer to clear bricks from the log. However, there is only one hammer for both players. The player must either pass the hammer to Billy or ask for the hammer from Billy (see Figure 4, right). The player can choose not to share the hammer, but it would make the level difficult — and, in some cases, impossible—to solve. In the future, if a player consistently exhibits anti-social behavior (e.g., not sharing the hammer with the peer), the game can scaffold the player towards more social game behaviors. The SEL goal of "asking for help" is further supported by giving the player an option to ask the scout leader to explain the game goals and mechanics.

Inquiry Levels and How SEL is Supported

Beanstalk and *Teeter Totter Go* engage students in inquiry practices such as allowing the player to make predictions based on their current knowledge, construct new hypotheses by comparing explanations of observations, and argue for (or abandon) the hypothesis using recorded or new observations. In each game, inquiry occurs at the end of each tier, and serves in part to reinforce what was learned in the preceding problem-solving levels and in part to introduce new ideas.

In *Beanstalk,* inquiry activities commence when sea gulls land on the beam; they will not leave until the situation has been clarified through inquiry. The game guides players through a predict-observe-explain cycle, a standard pattern in science education for the given age group. First, the player and the NPCs (Chicken and Crow) all make a prediction (Figure 2, right) as to what will happen when Chicken and Crow stop holding the beam steady. Invariably, the predictions conflict. When Chicken and Crow fly away, the player and characters observe whether the beam tips or balances, as way of testing their prediction. The player then is asked to provide an explanation by selecting a general rule that captures the observed behavior (Figure 5, left; the game speaks the words aloud since the target population often cannot read). The game then gives generic positive feedback. Throughout the inquiry activity, the NPCs model use of scientific terminology like "hypothesis," "investigation," "explanation," and "prediction." The current version of the game supports our third SEL goal (resolving disagreement constructively) in a limited manner, by modeling how, during collaborative inquiry, disagreement can occur (the characters invariably make different predictions) and how this specific type of disagreement can be resolved by careful observation. We plan for later versions of the game to support more elaborate discussion regarding competing predictions and hypotheses.

The inquiry activities in *Teeter Totter Go* follow a similar pattern as those in *Beanstalk*, but are extended to include a log book in which hypotheses and observations are recorded. Using the log book, the player considers a hypothesis in light of multiple observations. With respect to supporting SEL, the inquiry activities in *Teeter Totter Go* provide opportunities for discussion between the player and the virtual collaborator, Billy, in support of the SEL goal of "solving disagreements through interactions and discussions with peers" (see Figure 5, right). In the predict step of the predict-observe-explain inquiry process, the characters predict the outcome independently and therefore will sometimes make different predictions. When and if they do disagree, the game gives the player a choice of behaviors that represent varying degrees of social adeptness. The player can choose to "discuss/explain" his/

her answer (a pro-social behavior), tell Billy he is wrong (an anti-social behavior), change his/her answer (a mildly social behavior), or skip the discussion and go immediately to see the outcome (a non-social behavior). If a player behaves socially, he/she is rewarded with further social interactions with the peer. In this way, the game reinforces the goal of helping the child think about and explain the science phenomena. We plan to extend the game so that if a player consistently behaves anti-socially, the game will scaffold the player towards more social interactions.

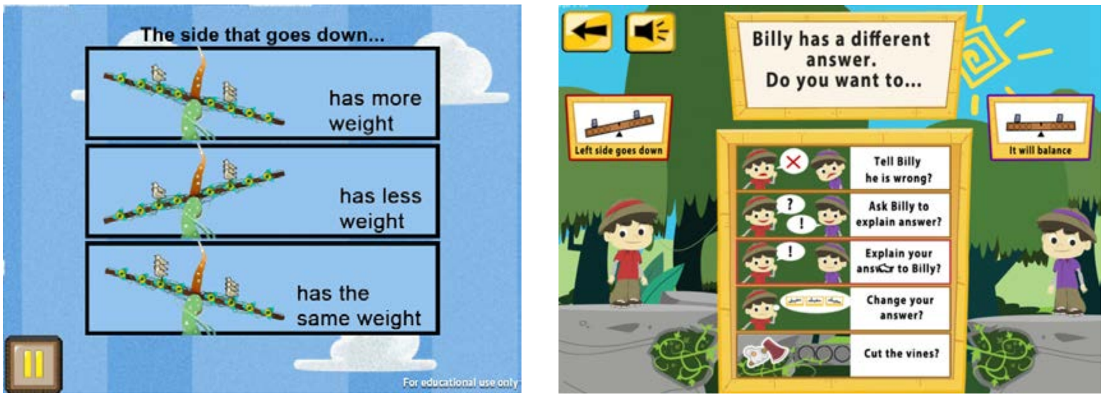

Figure 5: Inquiry in *Beanstalk* (left) and with SEL support in *Teeter Totter Go* (right)

Discussion and Conclusion

We have illustrated our approach to designing collaborative inquiry games for young children. Both *Beanstalk* and *Teeter Totter Go* have seen multiple cycles of playtesting and redesign and have been improved during these iterations. In addition, *Beanstalk* has been through an extensive redesign in order to better accomplish the inquiry and SEL goals. Feedback from children has been largely positive. *Beanstalk* has also been used in three classroom pilot studies, with over 200 students. We are analyzing the data about the success of *Beanstalk* in teaching the SEL and physics principles.

A major challenge in creating collaborative inquiry games like *Beanstalk* and *Teeter Totter Go* is how to best integrate compelling narrative and game play with effective support for scientific inquiry, social-emotional learning, and science content learning. In particular, it is challenging to combine problem solving and inquiry in a way that both are perceived as fun – rather than the inquiry activities being seen as an unwelcome interruption of the flow of the game. Feedback from the latest playtesting session with *Teeter Totter Go* suggests we have made progress toward that goal. In initial versions of the game, the students really liked the problem-solving levels but disliked the inquiry activities. Adding the villain, making him challenge the player to “figure it out,” and casting some inquiry levels as boss fights with the villain (not described above) made a substantial difference. These changes have pulled the inquiry activities into the narrative and the students have responded positively. The narrative context motivates and provides meaning to the inquiry activity (Dickey, 2006). The same can be said for how the narrative in *Beanstalk* envelops the inquiry activities.

While we believe that the educational goals that we are pursuing can be integrated in a synergistic way, many questions remain unanswered. As mentioned, we view the current versions of *Beanstalk* and *Teeter Totter Go* primarily as platforms for further investigation. For example, inquiry is important for science learning, but how can it best be integrated in a way that supports the narrative context of the game and moves it forward? Further, SEL is important, but if help seeking is more fun in a narrative context (e.g., because of wise cracks by Chicken and Crow), might it become a distraction? Does learning SEL skills while learning content and inquiry impose too much cognitive load? Does integrating SEL and content learning promote a healthier environment for learning? Does collaborative inquiry indeed provide good opportunities for social-emotional development? We plan to address questions like these through experiments, both in schools and through crowdsourcing (Andersen et al., 2011; Lomas, Forlizzi, & Koedinger, 2013). We anticipate that these experiments will yield interesting insight as to whether collaborative inquiry and SEL can be supported effectively in a game and whether they mutually reinforce each other.

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