Beanstalk: A Unity Game Addressing Balance Principles, Socio-Emotional Learning and Scientific Inquiry

Michael G. Christel, Scott Stevens, Matt Champer, John Balash, Sean Brice, Bryan Maher, Danny Hausmann, Nora Bastida, Chandana Bhargava, Weiwei Huo, Xun Zhang, Samantha Collier
Entertainment Technology Center
Carnegie Mellon University
Pittsburgh, USA
christel@cs.cmu.edu

Vincent Aleven, Ken Koedinger, Steven Dow, Carolyn Rosé, Jonathan Sewall, Mitra Fathollahpour, Chris Reid, Julia Brynn Flynn, Amos Glenn, Erik Harpstead
Human-Computer Interaction Institute
Carnegie Mellon University
Pittsburgh, USA
aleven@andrew.cmu.edu

Abstract— **Beanstalk is an educational game for children ages 6-10 teaching balance-fulcrum principles while folding in scientific inquiry and socio-emotional learning. This paper explores the incorporation of these additional dimensions using intrinsic motivation and a framing narrative. Four versions of the game are detailed, along with preliminary player data in a 2x2 pilot test with 64 children shaping the modifications of Beanstalk for much broader testing.**

Keywords— educational game, early childhood science education, intrinsic motivation, game development process, Unity game engine.

I. Introduction

Beanstalk is an online Unity game developed to teach children ages 6-10 scientific principles, socio-emotional learning (SEL), and scientific inquiry. The game is based on Siegler's cognitive development work with a balance scale [1], teaching principles governing the sum of cross products rule that can be used to determine whether a scale will balance, given a particular configuration of weights on each side of the fulcrum. The game levels are designed to help children progress through four increasingly sophisticated mental models identified by Siegler: (1) paying attention to weight, not distance; (2) considering distance, but only when weight is equal on both sides; (3) considering both weight and distance, with cues in congruity; (4) considering both the amount of weight and distance of weights from the fulcrum; if the cues suggest different outcomes, the sum of cross products rule is applied. The level design also respects the Lens of Flow as outlined in Schell's game design book [2] founded on earlier work [3], with level complexity increasing ideally to let the child player enjoy a rewarding enough experience to remain engaged and feel a sense of achievement without undue frustration. Table I outlines the level progression in the game.

Beanstalk also addresses SEL and scientific inquiry as a means to give the child player experience in constructing explanations, a scientific practice called out in the NRC report on new K-12 science education [4]. SEL aspects of the game include seeking assistance when encountering a problem, cooperating to accomplish a joint task, and solving problems through interactions. The *Beanstalk* game establishes five non-playable characters, i.e., the NPCs of Jack or Jackie, a friendly monster, a chicken, a crow, and a flock of seagulls. These NPCs allow for the practice of SEL and gaining skill in persisting through challenging levels, asking for help, cooperating, and discussing.

TABLE I. Tiers within Beanstalk, with Multiple Game Levels per Tier, Illustrating Increased Difficulty at Later Tiers

Tier	*Allow Mirroring*[a]	*Description of Levels Within Tier*
1	Yes	Distance constant; weight varies
2	Yes	Weight constant, distance varies, single items
3	Yes	Weight constant, distance varies, may have multiple items (bugs) on a single beam position
4	Yes	Weight and distance vary, may have multiple items (bugs) on multiple beam position
5	No	Weight and distance vary, some beam positions blocked out so mirrored solution not possible
6	No	Weight and distance vary, more difficult problems involving sums of weights at different distances
7	No	Challenge problems, including those requiring placement of items on both sides of beam fulcrum

[a] Prior work shows that mirroring, e.g., putting something 2 from fulcrum on right if shown something 2 from fulcrum on left, is easiest solution path but may be pure pattern matching rather than applying sum of cross products rule for balance problems: when mirroring solution is prohibited, then the difficulty of the problem at that game level increases.

Beanstalk offers inquiry levels that conclude each tier (where a tier is a set of problem levels) in the game such that the player needs to successfully pass the inquiry in order to proceed to the next tier. Bundling a children's game with all three of a science learning objective, SEL, and scientific inquiry is rarely if ever done: this paper discusses the design and implementation challenges in pulling the three objectives together.

A recent column questions whether educational games help students or are over-hyped [5]. It argues that engaging games can be decomposed along dimensions of interest, motivation, and attention [5], aligning with pivotal early work on

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educational games stressing the importance of intrinsic motivation [6][7]. Section II explores how the design of *Beanstalk* addresses intrinsic motivation. Section III illustrates the difference between the four versions of the game, implemented with a single code and art/sound asset base using the Unity 3D game engine, configured to deliver one of the four game experiences through an external xml configuration file. The results of testing four versions with 64 children in first through third grades concludes the paper: *Beanstalk* with and without SEL support and with and without inquiry levels. The interaction between having NPCs you converse with for SEL and working through the inquiry process are emphasized in reviewing the results of this pilot study.

II. The Importance of Intrinsic Motivation

Before producing *Beanstalk*, the developers created *RumbleBlocks* for the same young child demographic, noting the importance of narrative in keeping the child player interested in working through game levels of increasing complexity [8]. Interest in a game's theme can lead to interest in the underlying learning content [5]. The *Beanstalk* theme evolved over a year of playtests with dozens of children, producing changes such as the introduction of Jack or Jackie as the main protagonist dependent on whether the player was a boy or girl. The story had to move away from being "oh, this is just Jack and the Beanstalk" to something more. The story, presented to the child player with an introductory animated scene and musical score, shows a friendly monster on a moon sleeping with its teddy bear. The teddy bear drops into a cabin where Jack or Jackie sleeps, and a magic bean pops out of the teddy bear into a crack in the floor. A beanstalk sprouts, and a floor beam becomes the balance beam on the Beanstalk on which Jack(ie) is perched, now holding the teddy bear in a backpack to return to the monster. Successfully balancing the beam makes the beanstalk grow, higher and higher until it reaches the monster and the teddy bear is returned in the final victory scene. Child players understand the story, and are motivated to help the monster as it interjects audio cues of support to keep going from tier 1down at a farm-level view through tiers 2 and 3 in the sunny sky into twilight skies of tiers 4 and 5 and finally night skies in tiers 6 and 7. A screen shot of the game at tier 3 for a girl player (hence, Jackie on beam) is shown in Fig. 1.

The player needs to have choice to foster motivation in learners [7][9]. If the choice is too open-ended, then the task can be de-motivating and frustrating. If the choice is too strict, then the task is boring. The guidelines in [9] trace back not only to games for learning [6][7], but also to optimal flow [3] and recommended game design principles like the Lens of Flow [2]. For *Beanstalk*, consider Fig. 1: the pods on the beam that can be watered to grow flowers in order to balance the beam are lit (enabled) rather than shaded darkly (disabled). The four pods to the left of the fulcrum are all shaded and are not part of the player's choice range. The four pods to the right of the fulcrum are all lit and are in the choice range. The mouse cursor is hovering over the first position, and upon a click the player will plant a flower at this pod position. The simplest solution to the problem, based on Siegler's research [1], is mirroring: the child places two flowers at the first beam position to counter the two bugs at the first beam position on the other side of the fulcrum. (During the in-game tutorial after the opening narrative, the child learns that flowers weigh the same as bugs). To disable mirroring and make the choice more complex, this first pod to the right could be disabled (shaded). Then, the only remaining answer for this problem would be to plant a flower at the second beam position to the right, introducing the notion that distance can counter weight. The levels within the tiers are designed according to Table I's increased tier complexity, in order to move choice from easy to challenging, and facilitate the child player's progress through Siegler's mental models.

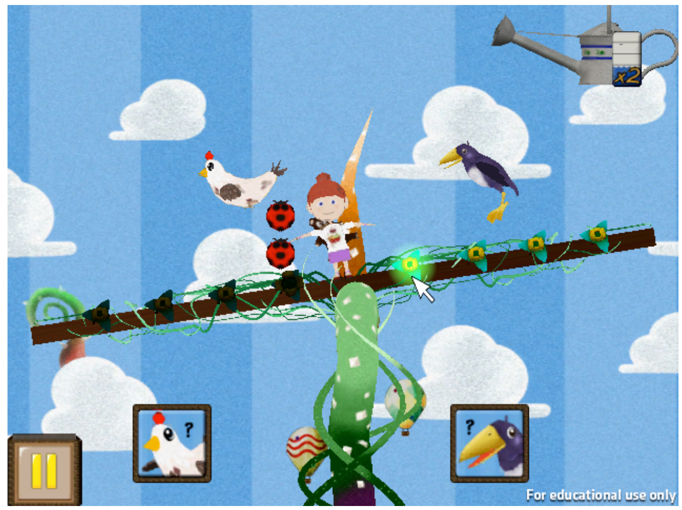

Fig. 1. Screen shot of Beanstalk, SEL version (chicken and crow chat with player, offer encouragement on their own and when prompted via a click or tap on their buttons at the bottom of the screen).

Importantly, it is the player's actions and not the game alone that increases problem complexity: the player is free to fail, with failure used as a learning opportunity [5][9]. If the player uses up their water (inventory shown in upper right on the watering can) and the beam is not balanced, Jackie falls down and the player is greeted again with that same problem. After a threshold is reached on consecutive failures, the player is offered visual and aural in-game help on how to proceed. After a number of successes are reached in a tier, the player advances to the next tier, perhaps with an intervening inquiry cycle. The player is in control as to how quickly the progression through tiers take place, with encouragement to explore his or her thoughts on how to achieve beam balance. Through such experimentation, the player establishes hypotheses regarding the sum of products rule governing beam balance. In versions of *Beanstalk* supporting an explicit inquiry cycle, these hypotheses are explicitly stated, and discussed with NPCs in the SEL with inquiry version of the game. For all four versions of the game, the balance-in-the-sky levels like shown in Figure 1 form the core of the game, where the child player gets to try out his or her ideas and see consequences of growing flowers at different points.

As suggested by [5] and argued more deeply in [9], a heightened state of attention can have a direct impact on learning. With *Beanstalk*, the use of a storybook theme, vibrant colors, playful animations, varying musical scores, rich sound effects, and appropriate visual effects to dress up everything from watering pods to flowers blooming to Jackie giggling or falling all help to draw the player into the game. Videos of playtests with children ages 6-10 have shown a deep focus and steady gaze of the child player when interacting with the game.

Malone's seminal work on intrinsically motivating instruction [6] investigated a series of games and identified the elements of challenge, fantasy, and curiosity as being key aspects of design that fostered engagement. In 1987 he and Lepper [7] expanded the list to include elements of choice and control. Dickie argues that while these works are still relevant and informative, game design has evolved since the era in which these studies were conducted, and suggests that within contemporary games, fantasy has developed into complex narrative structures with opportunities for exploration, collaboration, and challenge [9]. The narrative environment fosters motivation and serves as the organizational framework for the interactive environment [9]. Table 2 summarizes intrinsic motivation and *Beanstalk*'s design according to the framework posited by Dickie [9].

TABLE II. DESIGNING BEANSTALK TO MOTIVATE ITS PLAYERS/LEARNERS

Intrinsic Motivation	***Beanstalk Design Elements***
Choice	Male/female avatar, how many flowers to plant, where flowers should be planted, when to seek help, making predictions and hypotheses (inquiry treatments only)
Control	Strategies employed to balance beam
Collaboration	Working with chicken/crow (SEL treatments only)
Challenge	Problems equivalent to current level of skills
Achievement	Marked progress indications, elevated status higher in sky toward moon objective, advanced skills

One way player achievement is communicated is through a transition scene that concludes every tier, in which the camera position animates to show the player's current tier, then a checkmark to note that tier as done, then the next tier, and also a window into the end goal of reaching the monster. Fig. 2 communicates this sequence with a few screen shots.

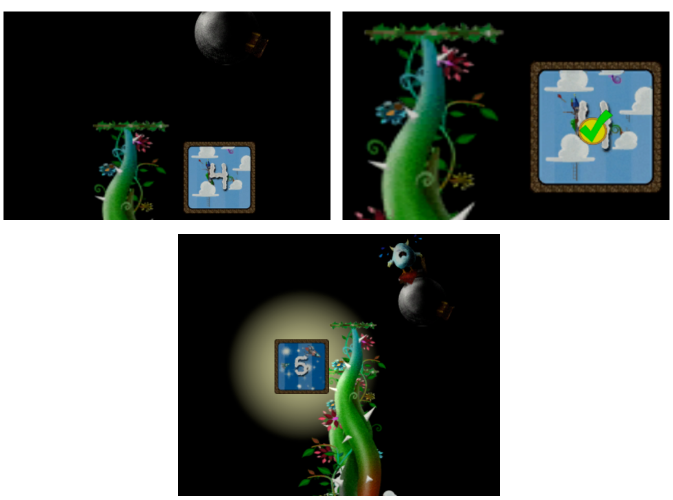

Fig. 2. Partial screen shots showing transition sequence: player finishes Tier 4, moves up Beanstalk closer to monster with Tier 5 to be set in star-lit sky, monster still crying for the dropped teddy bear being returned by player.

III. FOUR VERSIONS OF BEANSTALK

Four versions of Beanstalk were produced for testing, differing in whether there were NPCs supporting SEL, and whether tiers ended with inquiry cycles of predict-hypothesize-explain (PHE). The SEL versions had chicken, crow, seagulls, and a friendly monster interacting with the child player through animations and spoken dialog. The non-SEL versions kept the narrative framework of rescuing the monster's teddy bear, but did not include dialog with the seagulls or monster and did not include at all the chicken or crow. A game level for SEL is shown in Fig. 1; that same game level after a flower has been planted on the beam is shown in Fig. 3 for non-SEL version.

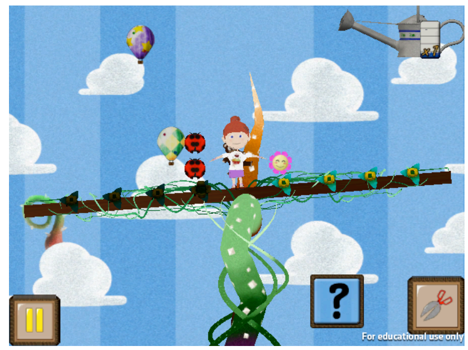

Fig. 3. Screen shot of Beanstalk, non-SEL version, one flower planted by player action and water remains in can to plant a second to balance beam.

The PHE version of the game ends each tier with three more scenes involving seagulls, and optionally crow and chicken. The PHE sequence begins with the chicken and crow holding the beam steady (SEL) or triangle supports doing so (non-SEL). The seagulls land, and the player then chooses from one of three predictions as to what will happen when the support is removed, as do the chicken, crow, and Jackie for the SEL version. For non-SEL plus PHE, there is no such discussion: the player just makes his or her prediction. The difference is shown in Fig. 4.

After a discussion with chicken and crow for SEL, or an anonymous narrator comment for non-SEL, the player is then prompted to make a hypothesis, choosing again from 3 choices completely filling the game screen. The hypothesis is then tested with a seagull animation on a freely floating beam and the results explained by chicken and crow (SEL) or the narrator (non-SEL). The information content is the same across all four versions of the game; the extra SEL support by including conversations with and between monster, seagulls, chicken, and crow is available only with SEL versions.

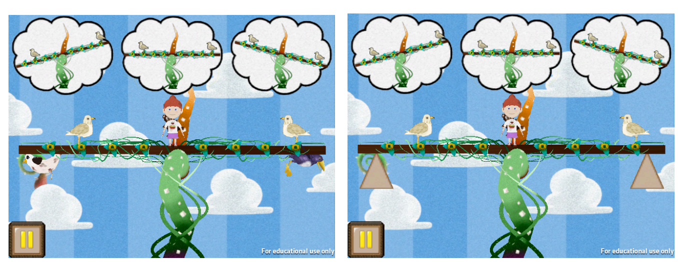

Fig. 4. Screen shot of Beanstalk, PHE versions (chicken and crow appear and talk in SEL-PHE version, generic blocks hold plank steady in non-SEL PHE version). The player is prompted to choose a prediction, leading to other inquiry steps of hypothesis and explanation in a 90-120 second sequence.

IV. PILOT TESTING THE FOUR BEANSTALK VERSIONS

64 children in grades 1-3, ages 6-9, made use of Beanstalk in December 2012. Each child used one version of the game for twenty minutes. One child left after nine minutes of play and is excluded from the summary. The remaining 63 produced the wins and losses as shown in Table III, where a level is won by balancing it, and lost by using up all the water in the can without achieving balance. The two-factor analysis of variance showed a significant main effect for the SEL factor on wins, $F(1,59) = 9.99$, $p < .01$, as well as a significant main effect for SEL on losses, $F(1,59) = 19.52$, $p < .0001$; it showed a significant main effect for the PHE factor as well on losses only, $F(1,59) = 8.47$, $p < .01$. There were no significant interaction effects. Clearly, the presence of SEL introduced a great deal of losses and suppressed wins, with an examination of the game log data revealing why.

TABLE III. RESULTS FROM 63 CHILD PLAYERS AGES 6-9, 20 MINUTE SESSION WITH *BEANSTALK*

4 Game Versions	***No-SEL No-PHE***	***SEL No-PHE***	***No-SEL PHE***	***SEL PHE***
Player Count	13	17	17	16
Wins	138	119	149	221
Losses	12	51	102	32
Win %	92%	70%	59%	87%

Mean Wins	***No-SEL***	***SEL***	**Totals**
No-PHE	13.8	8.8	11.2
PHE	10.6	7	8.6
Totals	12.4	7.9	

Mean Losses	***No-SEL***	***SEL***	**Totals**
No-PHE	2	6	4.1
PHE	0.92	3	2.1
Totals	1.5	4.5	

The game tracked child actions in an xml log suitable for inclusion in the Pittsburgh Science of Learning DataShop repository [10], i.e., each action was timestamped and identified with a session and player identifier, and marked with level, selection, action, and input qualifiers. 10,690 actions by the game system and player were logged across two days of testing. For SEL treatments, the child faced the unexpected challenge of a "cooperative" game level in which they had to ask the chicken to lay an egg on the beam, rather than water the spot directly, because that level forced cooperation by not providing enough water to solve the level without the chicken's help. In Fig. 1, if only the highlighted first beam slot were enabled (lit) and only one water was provided in the water can, then the chicken button would have to be clicked to trigger a dialogue with the chicken on where to lay an egg, with eggs weighing the same as flowers and bugs. Game logs showed that this forced SEL interaction did not work, needing a gentler introduction: players in the SEL treatments consistently failed such levels repeatedly.

As for the presence of PHE in the game triggering significantly fewer losses, perhaps it is due to instruction provided during predict/hypothesize/explain cycles noting the relevance of distance and weight to the balance problem. It may also be due to more time being spent in PHE cycles and less on balance problem levels. This early pilot test revealed an interesting pattern to be explored further in broader tests.

V. CONCLUSIONS AND FUTURE WORK

The December 2012 test showed that further investigation into SEL and non-SEL is worth retesting following the improvement of cooperation, gently introducing it with narrative and tutorial and/or always keeping it optional rather than forced. Longer total play sessions, an acceleration through early tiers on demonstrated success, and moving away from mirroring solutions in middle tiers 3-4 will also be done to advance skilled players more quickly to challenging levels: the 9-year-olds especially encountered few failures.

The most interesting question raised by the pilot data is whether inquiry instruction reduces player difficulty with subsequent more challenging game levels. More tests are needed to determine if folding in scientific inquiry measurement through interactive dialogues (e.g., Fig. 4) mixes well with the self-paced experimentation of the balance problem levels (e.g., Fig. 1). As noted in [5], corrective feedback if given prematurely might take away from a player's interest, motivation, and attention, but that same feedback can also provide beneficial instruction. The manner in which SEL folds into the game's evolution will also be explored, as it offers additional opportunities to reinforce feedback, keeping within the narrative framework, useful to motivate learners.

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