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Collaborative Gaming: Teaching Children About Complex Systems and Collective Behavior

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Abstract

Although games—including board games, video games, and Massive Multiplayer Online Games—have garnered significant attention in recent years for their impact on educational outcomes, a primary focus of this interest is the transfer of knowledge from game to nongame settings. Building on this literature, our research explores how game designs that promote either competitive or collaborative play may lead to differential outcomes including dramatically different and social dynamics. Using video transcribed for speech and gesture, we developed a grounded coding scheme to compare the experiences of a group of 40 early elementary students engaged in a uniquely designed board game, called HIVEMIND, to teach advanced science content to young children ages 6 to 9, which were organized around either (a) individual or (b) collective play. Findings indicate that, in collaborative mode, players were significantly more likely to make positive comments to others, talk on-topic, read instructions to other players, gaze toward the board as well as other players, and take shorter turns among other findings. Implications of this work for designing games and promoting collaborative and positive learning experiences are discussed.

Keywords

board game, collaboration, collaborative learning, collective, competition, debriefing, early elementary, educational outcome, learning, science education, simulation, social dynamics, video games

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Central to advances in our understanding of learning is a deeper understanding of designing for and analyzing complex learning environments, including the interactions that learners make in these environments. One form of interaction among learners that has received particular attention from researchers is *collaboration*. Research on collaboration has explored a number of factors, including the nature of various group arrangements, including peer teaching techniques; interactions with members of different gender, race, ability, and experience; and causes for successes and failures of group work (Webb & Palincsar, 1996). Furthermore, this substantial body of research provides compelling evidence that properly organized group work can lead to learning outcomes that exceed those of individual work. However, not all forms of group work are equally effective. For example, research has demonstrated that groups that are competitive in nature have poorer learning outcomes than do groups that have collaborative or cooperative forms of interaction (Barron, 2000, 2003; Cohen, 1994).

This body of research has particularly strong implications for the field of games in education, as most games incorporate some form of group interaction, whether it is collaborative or competitive (Berland & Duncan, 2012; Berland & Lee, 2010; Zagal, Rick, & Hsi, 2006). In our research, we build on the literature (Chen, 2012; Steinkuehler & Williams, 2006) to further investigate the role of collaboration and competition in these games and how interaction within games can be used to foster (or conversely undermine) learning. This is particularly important as we seek to infuse more games and games-based strategies into contemporary teaching and learning environments to guide our designs, recommendations, and to effectively foster a wide range of learning outcomes. Furthermore, games, like Massively Multiplayer Online Games (MMOGs) and even traditional board games, are ideal environments to advance our theoretical understanding of collaboration, as many games place collaboration at the core of the game mechanics.

Our study sought to inform our understanding of gaming models and theories of collaboration in the pursuit of learning. To more closely observe social outcomes of competitive versus collaborative gaming models within classroom contexts, we designed a unique board game, called HIVEMIND, to foster science-content learning focused on the complex communal behaviors of bees. Importantly, we designed HIVEMIND to support either (a) individual or (b) collective scoring systems, lending itself toward both competitive and collaborative modes of play, respectively. It is important to note that the content—honeybees working together to promote the life of the hive—suggests a collaborative game design. However, we found it useful to hone in on the impact of particular design decisions on gameplay and the simulated science content (Fennewald & Kievit-Kylar, 2012). Therefore, because we have often seen that students are motivated by competitive play and as a result are more likely to attend to design features which support their individual success, we decided to initially implement a competitive version of the game despite the potential contradiction between this model and the organization of honeybee hives, because we felt that the students would attend more consistently to the behaviors of bees which promote nectar collecting success—our learning goal. In this article, we contrast the case of this mismatched individualistic design with a more thematically aligned collaborative design to determine the implications of each for students' experiences of the game.

Our study took place within the context of a mixed-age, first- and second-grade classroom of 40 students. Although all students played our board game in teams of 4 players each, students were randomly assigned to play the game in a competitive or collaborative mode. We captured and transcribed video of students' gameplay experiences and then analyzed students' interactions using a coding scheme developed through multiple iterations of discourse analysis. Findings indicated that, in collaborative mode, players were significantly more likely to make positive comments to others, talk on-topic, read instructions to other players, gaze toward the board as well as other players, and take shorter turns than players in competitive-oriented mode. In addition, these players were also more likely to actively engage in discussing the science content (how honeybees collect nectar) during gameplay. Implications of this work for designing games to promote effective group learning experiences across all age ranges, but particularly for early elementary school are discussed.

Background

Collaboration, Games, and Learning

A growing body of research indicates that small-group interactions can be designed to support both specific content learning, and the development of more general inquiry practices, although a number of variables influence the potential efficacy of these interactions (e.g., Barron, 2000; Cohen, 1994; Webb & Palincsar, 1996). Because small-group interactions do not always produce positive learning results (Barron, 2003), researchers have stressed the importance of developing new ways to study the structure and quality of interactions (Barron, 2000; Cohen, 1994). Specifically, the orientation of participant interactions—whether the goal of the activity is collaborative or competitive in nature—has received close scrutiny. For example, Cohen (1994) has argued that small interdependent groups that are competitive in nature have poorer learning outcomes than do collaborative groups. This may be because competition undermines the ability of each student to play out their role in a manner that supports the group as a whole, thus rendering the group dysfunctional and unable to complete the task. In addition, research has suggested that to promote effective learning, groups interactions should be organized so that members: co-construct ideas; minimize conflict and controversy; are able to give and receive feedback as well as ask for elaboration or help; exhibit a general equity of participation; exhibit minimal social loafing; and have an equitable division of labor (Webb & Palincsar, 1996).

Of particular interest to the present study is Zagal et al's discussion of how games support various patterns of interaction among participants. Specifically, Zagal and colleagues (2006) point out that at least three types of interactions within games are presently acknowledged in game theory: competitive games, cooperative games, and collaborative games. Competitive games require players to form strategies in opposition to other players in the game (Jones, 2000). At the opposite end of the spectrum is collaborative games, which require that all participants work together as a team toward a shared outcome, where no sole winner exists (i.e., if the team wins/loses, everybody wins/loses). Sitting between these two, cooperative games model a situation where two or more individuals have interests that are "neither completely opposed nor completely coincident" (Nash, 2002). For the purposes of our research, we chose to focus on competitive and collaborative games as they are more distinct types of gameplay and represent two ends of this spectrum of interaction within games. Although several notable examples of collaborative games exist, including WORLD OF WARCRAFT (WoW; 2011) and similar MMOGs and, in nondigital games such as the PANDEMIC (2008) board game, not all games equally support collaboration. Therefore, one goal of the present study is to explore how to effectively integrate collaboration into educational games in a manner that supports learning outcomes.

Within the body of games research, we find several distinct advantages for observing the interactions that take place within face-to-face board game, as they facilitate collaborative play and design with fewer complications than in the digital domain (Berland & Lee, 2011). Not only are video games and the digital technologies that support them cost-intensive and resource-heavy, many of the games studied (e.g., EVERQUEST, 1999; WoW, QUEST ATLANTIS) are so multifaceted and expansive that it is difficult to contain and render transparent small-group interactions (Zagal et al., 2006). More problematic, Zagal et al. (2006) point out that games are typically structured as either competitive or cooperative; rare is the truly collaborative game where a group works together to share the payoffs and setbacks equally. Following Zagal and colleagues, we turn to the study of using board games to understand small-group interaction because board games offer self-contained interactions (with a set number of players and a limited number of action possibilities).

Games as Connecting to Content Area Learning

Over the past decade, games (and particularly video games) have attracted a great deal of attention from educators, parents, and scholars for their potential to immerse youth in challenging problems while offering appropriate scaffolds to encourage learning (Gee, 2004). Educators and researchers studied the design and implementation of novel games to support classroom learning with a goal of helping students make deep connections to disciplinary content across a range of disciplines, including science (Steinkuehler & Duncan, 2008), social studies (Squire, 2004, 2006) and the visual and performing arts (Peppler & Kafai, 2011; Peppler & Solomou, 2011). Of particular interest to this study is youths' connections to biological science learning through gameplay. Unlike previous studies on gamers' science learning, our investigation focuses on how early elementary school youth engage in board games to learn about complex biological systems, differentiating our study by its target age group, content area, and gaming environment; the previous studies into gamers' science learning listed above took place in multiuser virtual environments, focused on other content areas such as the water system or general scientific habits of mind, and targeted older players (middle school youth in one instance and participant data from online environments in the other where the ages of participants were unclear.)

Our original game, HIVEMIND, was designed to simulate aspects of honeybee nectar collection as an example of a "complex system" approachable to even young children (Danish, 2009; Danish, Peppler, Phelps, & Washington, 2011). Complex systems are a collection of interdependent and interrelated elements where the collection, or system, has properties that emerge from both the individual elements and their relationship to each other (Hmelo-Silver, Marathe, & Liu, 2007; Jacobson & Wilensky, 2006). In the case of honeybees collecting nectar, we can view the honeybees within a hive, the hive itself, and the flowers that the bees visit to collect nectar as a system. Honeybees collect nectar from flowers, converting it into honey which is then stored in the hive. As scout bees discover good sources of nectar, they return to the hive where they perform a "waggle dance" that indicates the direction and distance to the source of nectar. Other bees observe this dance and then set out in search of the identified flowers. The result is not only an incredibly efficient nectar collection operation, but also a highly adaptive one with honeybees ceasing to visit flowers that are no longer effective nectar sources, shifting rapidly to new abundant supplies. By helping students examine honeybees from this perspective, we can support them not only in understanding systems concepts which are quite generative and cut across multiple content domains (National Research Council, 2012; Sabelli, 2006), but also in developing a more robust understanding the specific biological system, and the way that it is organized.

HIVEMIND was designed as part of a larger curriculum (Danish et al., 2011) to help young children learn about honeybees collecting nectar as an example of the collective behavior important to a complex systems thinking. As noted below, the goal of implementing HIVEMIND within the larger curricular unit was to help students' reflect upon the random and probabilistic aspects of honeybee behaviors as they work collectively to gather nectar.

The HIVEMIND Board Game

The HIVEMIND board game appears similar to a familiar commercial "roll-and-move" game, such as Candyland, in that each user has a token (a picture of a bee) that they move around the board (see Figure 1). Students begin at the square labeled "start," and each turn they move along the arrows, rolling a six-sided die to determine which direction to proceed until they reach a square on the board. If the squares have special directions (draw a nectar card; return to start) these are resolved. Otherwise, players wait at the square until the beginning of their next turn. As players move their bee around the board, they also collect "nectar" which is then recorded on a score sheet. In one condition, players kept track of their nectar collection individually. By contrast, in the second condition, players stored their nectar collectively on one scoring sheet. In

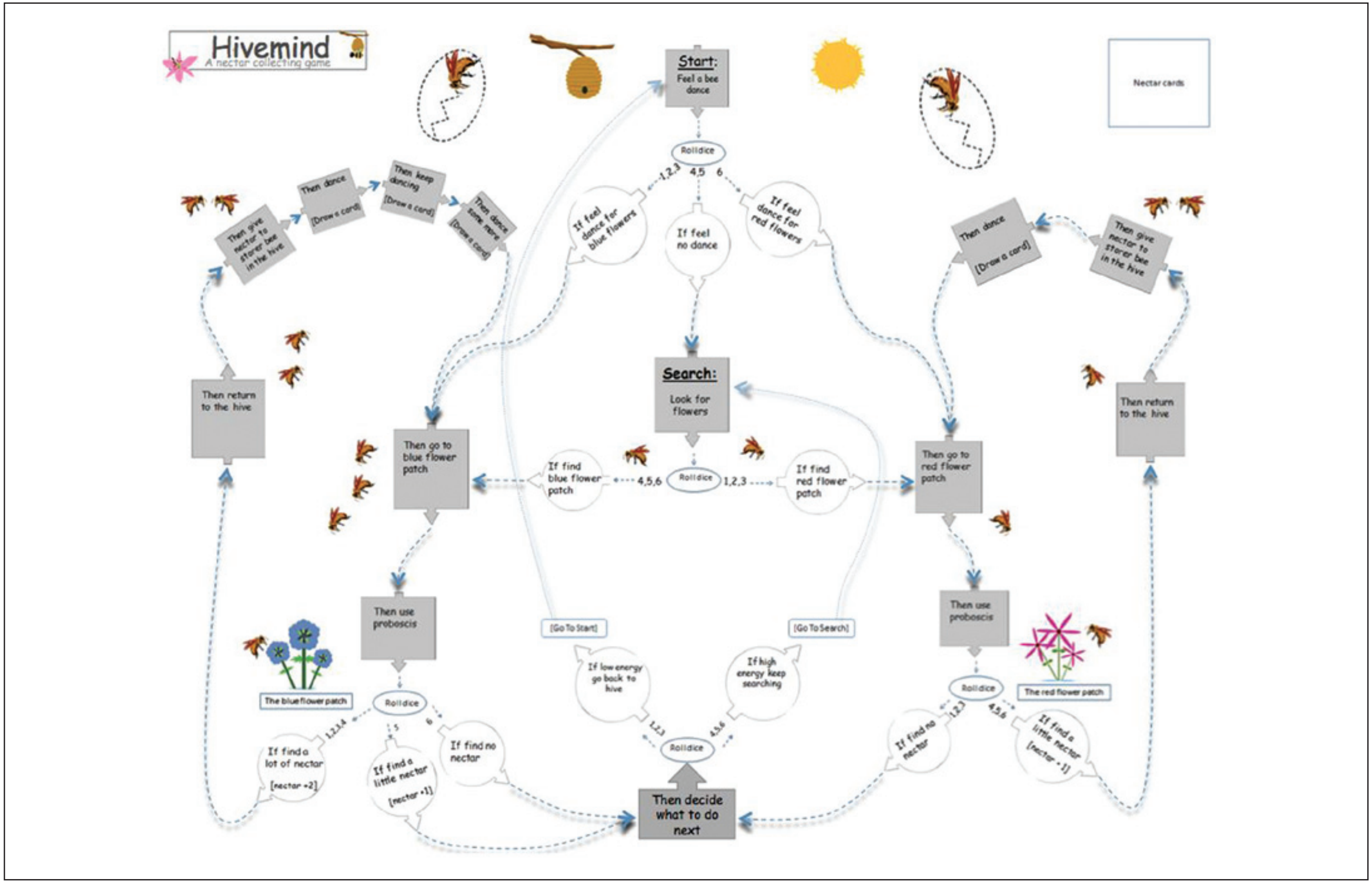

Figure 1. The HIVEMIND board (original 5′ × 3′).

both conditions, the players' goal in the game is to collect as much nectar as possible. While a shift in the scoring system would frequently necessitate a change in game mechanics, dynamics, and aesthetics (e.g., Hunicke, LeBlanc, & Zubek, 2004), we attempted to avoid this dramatic difference in order to see the local impact of this change upon students' experience of the game.

HIVEMIND was designed with two general instructional goals. First, it was designed to help students view the entire process of nectar collection in one extended representation that they could "explore" as they played the game. This was intended to complement other activities where students only engaged with one element of the process at a time (e.g., performing the dance). The bee's movement around the board is represented visually using symbols that are reminiscent of a flowchart. The board as a whole thus describes the movement of the bees through the nectar collection process and depicts the entire cycle of a bee finding a nectar source, dancing to tell other bees about it, and then returning to collect additional nectar. The flowchart symbols (i.e., the circles, boxes and arrows) were also employed in a number of representational-design activities with the students to help them describe the behavior of the bees, and thus were familiar to the students and helped establish continuity across activities.

The second instructional goal for HIVEMIND was to help the students recognize the decentralized nature of the honeybee hive, and in particular to appreciate the impact of several random and probabilistic elements of the honeybee nectar collection system. Viewing a system in terms of random, decentralized behaviors (e.g., the bees are not "simply doing what the queen tells them to," and are responding to environmental factors that one cannot consistently predict) is often challenging for students (Wilensky & Resnick, 1999). Specifically, we wanted to help students recognize that not all scout bees will find a flower that actually contains nectar, that this results in different behaviors (dancing to identify nectar location if they have found some, or observing such a dance if they have not), and that this is all part of an iterative process that is responsive to environmental conditions. Furthermore, once a bee begins to dance in the hive, the length of the dance determines how many other bees will perceive the dance (longer dances are used for better nectar sources), and an element of chance is involved in whether any given forager bee will see the dance performed by a specific other bee. The fact that the dance length influenced whether or not the dance was seen, and that not all bees observed the same dance was something many students did not initially understand, and was therefore a key aspect of the design of HIVEMIND.

To help model the randomness in these processes, dice were incorporated into the game. At several key moments during the game, the students roll dice which indicate what happens next. For example, when a scout bee is searching for a new flower, a roll of the dice indicates whether or not they discover one that is a good source of nectar. Similarly, when interacting with other bees in the hive, the dice determine whether the student has interacted with a bee that found the blue flower or the red flower, which represent a greater or smaller source of nectar. To help the students engage with the different probabilities within the system, not all of the decision points that utilize dice have the same probability of occurring.

To illustrate the incorporation of probabilities in HIVEMIND, consider the decision point immediately after the "start" square. The player is currently a forager bee and has a chance of interacting with a bee that is dancing to indicate the location of the blue flower (on a roll of 1, 2, or 3), not actually finding a bee that is dancing (a roll of 4 or 5), or finding a bee that is indicating the red flower (a roll of 6). This range was chosen to model the fact that a forager bee that finds a rich source of nectar (the blue flowers) will dance longer and therefore recruit more forager bees than a forager bee that found a moderate source of nectar (the red flower). Furthermore, additional foragers will also dance, increasing the likelihood of finding the rich source of nectar. Our goal was that students would notice these patterns as printed on the board and begin to recognize the reasons behind them, or discuss those patterns in the debriefing exercise as noted below.

In addition to reflecting upon the presence of randomness and probability in the system, our goal in representing these features was also to help the students to recognize two significant aggregate-level properties of the system and therefore the gameplay: we wanted students to begin to feel that more bees being aware of a nectar source speeds nectar collection, and that the benefit of collecting nectar quickly and efficiently is an increased likelihood of surviving the winter. Making this connection between the behaviors and the aggregate patterns that they support is a crucial and challenging learning goal. Students can readily learn these superficial behaviors such as observing the dance, and yet find it difficult to recognize what role or function those elements play (Hmelo-Silver et al., 2007). Our goal in highlighting these aggregate functions was to help make them more visible and intuitive to the students as they engaged deeply in the game. In particular, we wanted to help the students recognize how all of the bees working together helped support these processes, and thus the possibility of the hive surviving the winter—individual bees could not accomplish this on their own.

Salen and Zimmerman (2004) note that a game has to have both a clear goal and a win state. For both versions of HIVEMIND, the goal was to collect enough nectar to survive the oncoming winter, when the bees would no longer be able to collect nectar. As noted above, this goal was identified in order to support the students in reflecting upon the bee behaviors that make this possible. However, in identifying the appropriate win state, we faced a design tension around whether to develop a win state at the individual (the competitive mode), or a team level (the collaborative mode). The content suggests a collaborative goal in that honeybees work together for the survival of the hive as a whole, sometimes at the expense of individual bees. However, our experience with other activities within the curriculum (Peppler, Downton, Lindsay, & Hay, 2011) suggested that the students were more likely to focus on their own individual successes or failures as a way of reflecting upon the benefit of the behaviors of the specific bees. In other words, we hypothesized that students would be more likely to reflect upon the benefits of the bee dance for their individual bees. Therefore, we initially implemented an individual win state, rewarding the bee that collected the most nectar in the shortest amount of time. However, as indicated below, the students focused so heavily upon their own individual bees that they seemed to have frequently ignored both their peers and the system more broadly. Therefore, we adjusted the win state in the second implementation to privilege the hive as a whole, represented by the entire group of students.

Research Questions

We sought to address three overarching questions in this work:

Research Question 1: How did the game orientation—competitive or collaborative—influence student interactions and productivity during gameplay? More specifically, could we find a relationship between game context (competitive versus collaborative) and classroom behaviors, including the presence of positive and negative talk, the location of students' gaze, and the presence of individual (rather than team) references when discussing the score?

Research Question 2: In what ways do students/facilitators identify and try to correct emergent tensions during gameplay?

Research Question 3: How did the game orientation—competitive or collaborative—influence opportunities for learning during gameplay? What was the extent to which students' conversations were on-topic to the game? What tensions exist in the explicit learning goals between games focus and students' participation? Furthermore, could we find a relationship between game context (competitive vs. collaborative) and the presence of science talk?

Participants and Setting

The HIVEMIND game was played as part of a larger study designed to teach students about how honeybees collect nectar from a systems perspective (Danish et al., 2011). The participants were 40 first- and second-grade students (ages 6-9) in a mixed-age classroom in a public elementary school located in central Indiana (roughly 50% of the students were female). The majority of students at the school were White (90%) with only 17% of the students receiving free or reduced lunch.

Video Transcription and Coding

To analyze students' interactions during the two game conditions, we first transcribed the video record of the students' interactions with their peers and the teachers while playing the game. This resulted in a total of 1,548 utterances (39 utterances were identified as inaudible and were not transcribed). A total of 1,223 of these utterances were attributed to students, and the remaining 325 were attributed to either the researchers or teacher.

An iterative coding approach was then used to examine these interactions. First, following Erickson (2006), we reviewed the data iteratively, proposing potential

Table 1. Codes Applied to Student Utterances.

Code	Description
Off-topic Talk	Utterances not related to gameplay or science content
Game Talk	Utterances related to gameplay (e.g., turn taking, rolling dice, moving pieces)
Score Talk	Utterances related to gaining points or adding points to score sheet
Science Talk	Utterance related to bee activity. This includes collection of nectar, hive activity, and bees feeling you dance
Valence	Positive, negative, or neutral utterances directed toward team players. Positive utterances were those that supported other students such as "go team, go," and negative utterances were those that discouraged peers' or critiqued their behavior such as "don't be so rejoicing," "that's not nice"
Scoring Orientation	A subset of talk about the game score that differentiates whether utterances were individually oriented, collaboratively oriented, or unspecified
Redirect to Collective	Utterances made by students or facilitators to guide group/ individuals to work collaboratively as a team instead of competing with each other
Redirect to On-Task Activities	Utterances made by students or facilitators to guide group/ individuals back to game board practices/activities

analytic schemes and then refining them as additional episodes suggested alternative or refined analyses. We then worked from these analyses to articulate a coding scheme that would capture the key elements of students' interactions in response to the research questions. In particular, our goal was to develop a coding scheme that identified the content of students' talk in terms of whether the focus was on various aspects of the science, gameplay, or off-topic, and their orientation toward the ongoing game (e.g., whether it was positive or negative, oriented toward collaborative or individual goals, etc.). Table 1 summarizes the codes that were developed.

To analyze how the structure of the game impacts the quality of interactions, we implemented two versions of the HIVEMIND, a competitive and a collaborative version. In both cases, students played in small groups sitting around the board, and interacted with their peers throughout the gaming session. We used several ways to measure the quality of collaborative interactions including measuring students' engagement in the game and students' positive contributions to the game and to one another. To measure engagement, we tracked how often students' talk was on-topic and how often students' eye-gaze was situated on the activity. To measure whether the interactions were positive or not, we attended to the types of comments students made to one another (explicitly encouraging comments were deemed positive while explicitly antagonistic comments were deemed negative). The speed of turn taking and the amount of help students offered others during their turn further served as indicators of positive engagement.

Results

Question 1: How Did the Game Orientation—Competitive or Collaborative—Influence Student Interactions and Productivity During Gameplay?

Our first analysis examines the relationship between the two gaming conditions and the resulting group social dynamics through an analysis of students' video-documented utterances and gestures. We believe that teacher and researcher utterances contributed to the nature of the gaming context, and so their influence is captured as part of the student responses to the gaming context. To explore the relationship between gaming condition (i.e., competitive vs. collaborative) and the presence of positive and negative talk during gameplay, we coded students' interactions along three dimensions: valence, gaze, turn taking (i.e., a measure of productivity), and general attitude or sportsmanship in regard to the scoring.

To capture the valence of student talk, we marked an utterance as having a positive valence if students cheered on their fellow players, offered them reassurance after something bad happened, or expressed gratitude for help they received. Utterances that were marked as having a negative valence included instances where students explicitly accused their fellow peers of cheating, gloating, acting rudely, or dice hoarding. In addition, we coded utterances as negative when students made discouraging or resentful comments. Identifying the presence of a negative comment was particularly important because our data indicate that a single negative comment can lead students to argue, withdraw, or become distracted. Take for example the following discussion (Excerpt 1). This excerpt took place shortly after the students noted that Eliza was likely to lose and then Renata scored four nectar points on her turn, potentially setting her up to win.

Excerpt 1. Negative comments leading to arguments

1. Julia: Don't be so rejoicing Renata, that's not nice.
   [Eliza chews on her t-shirt saying nothing throughout the following exchange]
2. Hillary: She's not stopping it. If you ask her to stop she will not stop.
3. Renata: I try to.
4. Hillary: Well I asked you before and you did not stop.
5. Julia: Now I ask you and you don't stop.

In this example, gameplay stopped when Renata was accused of gloating. Although a facilitator later attempted to redirect the students' attention to gameplay, the general mood of the players appeared to have worsened as they resumed:

Excerpt 2. Negative comments further leading to withdrawn and distracted behavior

1. Hillary [Reading the game board directions]: Go to red flower patch.
2. Owen: Hey, Hillary. Hillary. [Unsuccessfully bids for Hillary's attention]

Table 2. Instances of Positive and Negative Interactions Across Competitive and Collaborative Modes of Gameplay.

	Positive	Negative
Competitive	7	30
Collaborative	22	2

3. Hillary [As if defeated]: I have to go here again [the red flower patch contains little nectar compared with the blue flower patch].
   [Julia begins playing with a dry erase easel withdrawing her attention from the game]
4. Facilitator 3: Well your turn ends here.
5. Owen: I feel sad. I'm the only boy here. [Grunts and tosses his arms up in the air]

Although these comments were not marked as explicitly negative (again because negative valence of talk is somewhat subjective to measure we only counted utterances that were negative enough that multiple judges could agree that they counted as negative talk), students gave the impression that they were dejected, unhappy, and disinterested in the gameplay. This example is taken from the board game situated in a competitive context and is representative of the types of negative mood and disruptive actions that followed negative exchanges between students.

To determine whether or not a significant difference existed in the proportions of positive and negative valences across the competitive and collaborative condition, we conducted a chi-square test. Students in the competitive context were significantly less likely than their collaborative gaming counterparts to make positive comments to their peer, χ^2 (2, N = 1,223) = 40.618, $p < .001$. In addition, students in the competitive context were significantly more likely to make negative comments to their peers (see Table 2). These findings align with our and the classroom teachers' observations of the general classroom atmosphere during both conditions.

Furthermore, we were interested in capturing and analyzing other aspects of the group dynamics. Of particular concern in the literature on collaboration, is the predominance of "social loafing" or what we might consider to be off-task activity or general disengagement. We looked more closely at three aspects of social loafing, including gaze, turn taking, and general attitude.

An analysis of gaze was intended to help us determine whether or not the students appeared to be engaged with the ongoing activity, or distracted and attending to other things. An examination of students' gaze during the activity revealed that students were much more likely to gaze away from the game and the other players during conversations in the competitive condition (over 33% of the time one or more student's gaze was turned away from the activity), then in the collaborative condition (only 6.3% of the time). These differences were statistically significant, χ^2 (1, N = 1,223) = 134.799, $p < .001$. These results suggest that students' interactions in the collaborative condition were generally more positive and directed toward actual gameplay. As a

Table 3. Competitive vs. Collaborative Framing of Scores Between Gameplay Modes.

	Competitive attitude	Collaborative attitude	Neither explicitly competitive nor collaborative	Total score talk
Definition and examples	Describes score competitively: —"I'm getting the most." —"I'm catching up to you, Renata."	Describes score collaboratively: —"We got two more." —"We're almost about to be full."	Describes score, but does not attribute points to individual or collaborative: —"Four." —" . . .plus two nectar."	
Competitive context	46 (56.1%)	4 (4.8%)	32 (39.1%)	82
Collaborative context	14 (16%)	25 (28.4%)	49 (55.6%)	88

result, we hypothesized that students were able to progress more quickly through the game in the collaborative context than the competitive context because we believed that they were more focused on the game and gameplay and less frequently distracted. Moving through the rounds quickly is a valuable pragmatic measure given the fact that students needed to be able to move through a number of rounds in the game to begin to see the emergent patterns within the system of nectar collection, and given limited time in the classroom. To examine the amount of time taken to progress through game rounds, we evaluated the length and number of game rounds in the two conditions. On average, students in the competitive condition required 2 minutes 38 seconds to complete a round whereas students in the collaborative condition only required 1 minute 59 seconds. This represents a 25% shorter round on average, and suggests that students could engage in more productive rounds in the same amount of time within the collaborative condition than in the competitive.

Finally, we wanted to see if students appropriated a competitive or collaborative attitude when discussing the scores of their hive. To measure this we analyzed whether students talked as if their hive was collecting nectar points as a team (in which they could win or lose as a whole) or if they talked as if bees were in individual competition to collect more nectar than other bees of the same hive (with distinct winners and losers; see Table 3). We searched only within student-generated utterances that were score-related. Within score-related talk, the competitive conditions were significantly more likely than the collaborative conditions to refer to the hive as a collection of individuals scoring points for themselves, χ^2 $(2, N = 170) = 35.674, p < .001$. Not surprisingly, we found that the students playing the collaboratively framed game discussed their scores as team-score with individuals indiscriminately contributing to the total. We find this result affirms that students appropriated the competitive and the collaborative framing of the designed board game activity in their attitudes toward gameplay.

Question 2: In What Ways Do Students/Facilitators Identify and Try to Correct Emergent Tensions During Gameplay?

To determine how students and facilitators responded to the emerging tensions between individual and collaborative attitudes and on- and off-topic talk, we coded conversations for utterances whose functions were to (a) redirect students to consider their efforts as part of a collective hive and (b) redirect students to be on-task during the game. In these analyses, we included audible comments made by both facilitators and students.

First, we calculated how frequently across the two conditions (individualistic and collaborative learning contexts) facilitators and students were making comments to redirect focus to the collaborative efforts of the hive (e.g., “Bees are supposed to support each other aren’t they,” “The *entire* hive got two nectars”) and then ran a chi-square test to assess whether these differences were meaningful. We found no significant difference across the two conditions: χ^2 (1, N = 1,547) = 0.037, p = .498. We read this result to mean that across both conditions facilitators and students were reminding one another of the intended collaborative nature of the game, but that despite their best efforts, students in the individualistic condition (as we saw earlier) appropriated a competitive attitude toward the hive.

Next, we ran an additional chi-square text to determine whether significant differences existed in how frequently across the two conditions facilitators and students produced comments whose function was to redirect students to be on-task (e.g., “It’s your turn,” “who’s next?”). In this case we found a significant difference between the two conditions, χ^2 (1, N = 1,547) = 12, $p < .001$, with more students in the individualistic, competitive condition being prompted to act on-task. Specifically, in the individualistic condition we found 58 cases of students being redirected to be on-task (or roughly 6% of the time), whereas in the collaborative condition we found only 12 cases (2.1% of the time). This means that students in the individualistic, competitive context were 3 times more likely to be asked to redirect their attention to the activity at hand, than in the collaborative context. Despite this additional encouragement, however, students were more likely to be off-task (not talking about the game or the science content) and disengaged from the science content of the games as our last set of findings indicates.

Question 3: How Did the Game Orientation—Competitive or Collaborative—Influence Opportunities for Learning During Gameplay?

As we know from research, group dynamics like those illustrated above can play a major role in effective learning outcomes (e.g., Barron, 2000, 2003; Cohen, 1994). In our study, we took a closer look and examined various opportunities for learning during gameplay, which focused on the amount of on-top talk, the occurrence of science talk, and the major tensions in the group activity that negatively impacted learning opportunities.

The topic of students' talk (on-topic or off-topic) was analyzed to further capture students' engagement with the game across conditions. Students' talk was considered on-topic if it referred to any aspect of gameplay (the rules, the board, coordinating activity, and so on) or the science content covered by the game. Just as students in the competitive context talked more negatively to one another, their talk also consisted of more off-topic talk than the collaboratively framed game, and this difference was statistically significant, χ^2 (1, N = 1,223) = 29.395, $p < .001$. Specifically the competitive context group uttered 146 comments (20.8% or just over one fifth of their comments) that were off-topic while the collaborative group only voiced 43 off-topic comments (8.7% or less than one tenth of their comments).

To explore further the potential benefits of the on-topic talk in the collaborative condition, we then examined on-topic talk more closely to determine how much of students' talk across the two conditions related to the science content as opposed to game-related discussions. The majority of science talk we witnessed students' engaging with came from students' reading the science content from the game board or game cards (such as "pass the nectar to the storer bee," "Three bees see you dance"). We also marked inference level comments in which students discussed the patterns they noticed within the broader activity system of nectar collection. These included relationships between the quality of nectar between flowers on the board, the flight paths of their bees toward these flowers, and their hive's overall nectar collection. Sample utterances included, "This one's better [pointing to blue flower] because it has 2 nectars" and "The entire hive's getting more nectar!" A higher proportion of this science talk came from students in the collaborative context than in the competitive context, and this difference was statistically significant, χ^2 (2, N = 1,223) = 12.180, $p = .002$.

Although the science content discussed during the game was not particularly rich and the inference level comments were rare during gameplay, they were prevalent in both groups' discussions during the postgame debrief session, providing evidence that students did pick up on the patterns we had designed the game to experientially illustrate, which we discuss more fully in the game debrief section of this article. However, what struck us as particularly important about the science talk during the game is the collaborative nature driving the interactions behind the talk in which students helped one another read the cards out loud and played active listeners when the science was being read. The collaborative nature of students' reading and listening to the science content was a persistent feature of students' interactions in the collaborative condition, but not in the competitive condition.

Taken together, we noticed three major tensions emerge in the activity system of playing this game for the competitive condition that were virtually absent in the collaborative condition. First, the competitive condition does not accurately portray the collaborative enterprise of bees working together to collect nectar. Thus, we found a mismatch between how students acted as bees in the game, and how bees actually behave in real life.

Second, the students in the competitive condition lost interest in their fellow player's turns, which may have made it difficult for the students to grasp the holistic patterns of nectar collection emerging from the probabilistic nature of the bee dances represented at the hive. Without the students working together as a team—not just of bees, but a team of students collaborating to help each other play the game efficiently—rounds took considerably longer and thus the game's emergent holistic patterns took longer to appear as well. Thus, the designed lessons of the game may not have become salient in a timely fashion for the players, if at all for the players who chose only to pay attention to their own turns. This may also be due to other factors, including, but not limited to the age range of our participants (i.e., younger participants may not be as interested in competitive games) or perhaps the function of playing serious games in a schooling environment (where overt competition is less valued in academic contexts).

Finally, playing a game in which negative comments and antagonistic interactions are occurring runs counter to the fundamental appeal of games: their fun factor. To demonstrate how these tensions permeated the competitive context, and what their absence looks like as best expressed in the collaborative context we now take a closer look at a representative excerpt.

Excerpt 3: Students playing in the competitively framed game

1. Beverly: Two more nectars for you. So color in four more.
2. Josiah: Four. I get to color in four. Oh my God. I am so winning.
   [Josiah turns back to board game, leaning in over score sheet. Edgar leans over a chair near the game board, looking down at the score sheet, but not at the game. Chelsea whispers to Beverly]
3. Beverly [to Chelsea]: Now, now, roll. Now, now, now, now. Where's the dice?
4. Josiah [Counting his score to himself]: Yes!
5. Edgar [From chair]: I only got one, one percent of nectars.
6. Chelsea: Where's the dice?
7. Josiah: I got six.
8. Chelsea: Where's the dice?
9. Josiah: Right here [tosses dice past Chelsea. Chelsea retrieves it].
   [Josiah wanders off the screen and Edgar sits down facing Josiah away from the game]
10. Chelsea [Announcing her roll]: Six.
    [Josiah and Edgar talk to each other away from the board game]
11. Beverly [to Chelsea]: So now you get to draw a card.
12. Chelsea: Oooh.
13. Chelsea [Drawing a card]: What does it say?
14. Beverly: Three bees (inaudible—spoken softly)
15. Chelsea: Three [Josiah and Edgar move in closer to the game, but still talk off-topic and ignore gameplay. Chelsea reaches for the scorecard and Beverly grabs the die and rolls it]

16. Beverly [Moves her piece silently]: Can you color two on mine, like just one more?
17. Beverly [To Chelsea]: Will you color in?
18. Facilitator: Are you guys paying attention to the game?
19. Josiah: Whose turn is it?
20. Beverly: Mine. Oh, wait—yours.
21. Josiah: Well, its going so slow around.

The three major tensions discussed earlier play themselves out throughout this excerpt of student dialogue. First, the players take on a competitive and competitive role when scoring their nectar collection. This can be seen with Beverly's opening comment in Line 1 when she tells Josiah that he, not the hive, has collected four units of nectar for the turn. Josiah responds by declaring himself to be winner of the game thus far. Edgar takes on the role of the loser in Line 5 by claiming that he only has one nectar (or 1% of nectar as he saw it). Yet, bees within a hive act collaboratively and cooperatively; hence the tension between the students' roles as bees and the way bees actually behave. Second, players tended to only pay attention to their turns, if paying attention at all. In this case, Josiah and Edgar pay no attention to Beverly and Chelsea, yet if they are to fully grasp the holistic patterns of nectar collection they must take note of the movement of all the bees, not just their own individual bees. Finally, Edgar appears despondent throughout (self-identifying as a loser and facing away from the board) suggesting to us that he did not find the game particularly fun. Although these tensions persisted through each of the videotaped competitive groups, they were absent in the collaborative groups' gameplay.

Game Debrief

We completed both versions of the HIVEMIND game with a whole-group debrief session. The primary classroom teacher led the debriefing session, although the researchers were present and occasionally interjected clarifying questions. Despite differences in gameplay, the debriefs were structured quite similarly. Each session included two parts: First, a discussion of what students noticed in the game, with a focus on the behaviors of the bees; and, second, a discussion of what the students would change in the game. In both cases the students sat in a circle with a copy of the board game in the middle for their reference. On both days the students were also asked first to share their general impressions followed by facilitator prompts to explore additional information. The teacher and researchers made use of these prompts to help make visible any patterns in the honeybee behavior that the students did not initially note. For example, one of the researchers told the students that he noticed that sometimes the bee danced for a brief time, and sometimes for a long time and asked what the students felt might have been the reason for that.

The debrief sessions on both days uncovered that at least some of the students in both conditions did in fact note the properties of the system that the game was designed to highlight. For example, students in both conditions noted that the bees did not all go to the same flower, but that some bees might go to the blue flower, and some to the red. In other words, they were beginning to note that not all of the bees were visiting the first flower that was discovered to have nectar. Furthermore, when the students in the collaborative discussion were asked why more bees visited the blue flower patch, a student responded by saying

> well what I think was the one to the blue flower had like the numbers were like easier to roll, like 1, 2, 3, 4 and like 5, 6 and the other thing was like . . . because um maybe the bees saw or felt that there was more nectar in one spot and not so many in the other.

The student was referring to the die roles corresponding to each flower, and this response represents a preliminary understanding of the idea that randomness existed in the system and that not all outcomes were equally probable. While it is difficult in these group discussions to determine the extent to which each student truly appreciated the scientific phenomena being discussed, it is encouraging that a number of students were noting these properties of the system and describing them for their peers' benefits.

The second half of the debrief focused on whether the students enjoyed the game and how they would improve it. In both conditions the students all enthusiastically raised their hands to suggest that they would play the game again. In fact, the teacher later reported to us that the students did bring the game out of their own accord when they had to play in the classroom during their recess because it was raining outside. However, while the students did enjoy the game, they were also willing to share their critiques.

Some of the students' suggestions about how to make the game "better" revealed an appreciation for the system being described. For example, a number of students in the collaborative condition also suggested opportunities to improve the game by adding realistic elements such as having more bees, or more flowers. Another student suggested that we include animals that might disrupt the collection of nectar. The idea of animals as disruptive for the bees, particularly bears, were mentioned frequently in the books that the students read about honeybees. An additional related suggestion to make the game more realistic was to provide a mechanism for nectar disappearing, although the student did not suggest what conditions might cause this as the facilitator noted that the nectar does get eaten during winter (after the game concludes).

However, not all student suggestions focused on the scientific accuracy of the game as many students also wanted to make it more fun, or more like other games they were familiar with. For example, one student noted that they would prefer it if each bee was guaranteed to find some nectar after several turns because this would make it more fun. While it may be helpful to redesign the game in a manner that can both highlight this feature and engage more students, it also provided an opportunity for the facilitators to point out to the students that this mirrored the possibilities in a real beehive where some bees might not find a good source of nectar on all trips. Other critiques and suggestions included a request to have more color in the game and to have three-dimensional pieces that they could interact with. One student even suggested the game include real honey that they could eat as they played.

Finally, it is important to note the brief comments that students in each condition made regarding the orientation of play. One student in the competitive condition actually noted that the bees were working together despite the fact that the game was not oriented in that way, saying,

> I learned that bees can go everywhere, and um they work as a team. They don't go like this is my nectar and I'm not going to give you some. They don't do it like that. They do it as a team like the whole hive does it.

In contrast, one of the students in the collaborative condition suggested that it should be more like a real board game:

> I think it should be like everybody for himself, like teams, to make it more like a real board game.

While the student seemed satisfied with a proposal that different hives might compete with each other instead of individual bees, which would be unrealistic, this does highlight a real tension in designing this kind of educational board game—students expect games to be competitive even when they emulate a collective system that appears to more closely mirror collaborative interactions. Fortunately, this confusion does not seem to have negatively impacted students' learning experiences with the game.

Discussion

Increasingly, researchers and designers are exploring the potential of games to support learning in both formal and informal learning environments. Given the focus on how to design these games and align them with curricular objectives, however, less attention has been paid to how classroom activities might be organized around games that support curricular learning. Our findings suggest that organization of gameplay, and in particular the competitive or collaborative nature of gameplay can dramatically influence what students get out of the experience, both in terms of the apparent affective tone of their interactions, and the aspects of the content that are explored. Furthermore, the decision to make a game either collaborative or competitive should be about more than just the kind of classroom environment one wants to support, or the fact that certain collaborative interactions are likely to promote content-oriented reflection or discussion. Rather, this decision should also take into account the very nature of the content being studied, and whether a natural mapping occurred between the content to be studied and the different forms of gameplay that might be employed.

In the present example, HIVEMIND was designed to help students explore the process through which honeybees collect nectar. Specifically, the board and mechanics were designed to help direct students' attention to the random and probabilistic aspects of the system. In this regard, the design appears to have been a success as a number of students noted these features as a result of their exploration of the game board during play. However, the two iterations of the game design each attempt to direct students' attention to these concepts through a different win state and therefore a different framing as competitive or collaborative. Specifically, our previous experiences in this classroom had indicated that the students were interested in individual success, and therefore more likely to attend to the conditions that supported their success. While it is true that the individual condition drove student attention toward winning, it also introduced some new challenges into the classroom environment and created a number of tensions. We then reimplemented the game with a more collaborative framing and were pleasantly surprised that the students were even more interested in the game and continued to attend to the key concepts as represented through the game.

This shift was, however, about more than just the nature of the classroom interactions, but was more about the alignment between these interactions and the content itself. One of the key ideas in teaching about honeybees is that they the individual bees all contribute to the collective health and success of the hive as a whole, not just to their own well-being. In fact, biologists have documented that bees and other insects will engage in behaviors that ultimately lead to the sacrifice of individual insects in favor of the hive as a whole. Our findings suggest that when gameplay mirrored this collaborative organization, it promoted more engaged, positive, and reflective play. In contrast, a disconnect arose between the game's organization and science content, students were not only competitive to the detriment of the learning goals, but they appeared to notice this disconnect and strive to repair it. Students' observations of this disconnect and their attempts to repair it are a key finding here because it shows how attuned even young students may be to the alignment between a game's theme and mechanics.

Future research into students' understanding of this alignment is likely to prove fruitful. In particular, we see two possible directions. First, it will be useful to more systematically explore the relationship between students' affective and learning outcomes and their perception of the alignment between game theme and mechanics. While the debrief session reported in this article suggests that no dramatic differences occurred after only one gaming session, our observations suggest that repeated play would have likely produced more noticeable contrasts due to the dramatic differences in students' attention. Second, we believe that future design studies have the potential to explicitly explore this alignment and misalignment with the goal of promoting deep reflection. For example, it may be possible to intentionally violate a principle such as cooperation in honeybees to promote rich discussion during the debrief about how competition is, in this case, less likely to lead to success.

In short, it is important for research into the role of games to support learning in classroom environments to expand to recognize the potential benefits and pitfalls of identifying and exploring the overlap between different game mechanics, and the nature of the content being studied. In educational settings, game mechanics do more than just result in a fun game, they influence the classroom culture, students' interactions with their peers, and the potential of the game to elucidate important aspects of the content being studied.

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