# Rainbow Agents: A Collaborative Game For Computational Literacy

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## Abstract
This paper describes the design of a collaborative game, called *Rainbow Agents*, that has been created to promote computational literacy through play. In *Rainbow Agents*, players engage directly with computational concepts by programming agents to plant and maintain a shared garden space. *Rainbow Agents* was designed to encourage collaborative play and shared sense-making from groups who are typically underrepresented in computer science. In this paper, we discuss how that design goal informed the mechanics of the game, and how each of those mechanics affords different goal alignments towards gameplay (e.g. competitive versus collaborative). We apply this framework using a case from an early implementation, describing how player goal alignments towards the game changed within the course of a single play session. We conclude by discussing avenues of future work as we begin data collection in two heavily diverse science museum locations.



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## Author Keywords
Collaborative learning; Museum exhibits; Museum design; Game design; Competitive games; Collaborative games; Cooperative learning

## CCS Concepts
• CCS → Human-centered computing → Collaborative and social computing → **Collaborative and social computing design and evaluation methods**

## Introduction
Early formative experiences with playful computer science education (CSed) can strengthen an interest, and pathway towards pursuing computer science as both a career and a hobby [3,8,21]. Learning

experiences that draw on the social and cognitive resources of underrepresented groups in computer science domains can aid learners in overcoming the endemic structural discrimination which has led to an enduring participation gap in CSed [7,9,25]. Museums are well positioned to serve as the setting for delivering CSed experiences that engage learners in complex, playful experiences, which can be difficult for underrepresented populations to access in traditional school settings [24]. Likewise, games designed for collaborative social interaction among participants present especially rich possibilities, due to the active, engaging, and constructive nature of collaborative play [4,28]. In this paper, we present Rainbow Agents, a museum-based game designed to promote computational pathways for populations typically underrepresented in CSed. We first describe the design of the game, tracing several of its core mechanics to concepts of computational literacy, and the broader goals of promoting meaningful construction and collaboration within that domain. We then report on a rich case from a beta implementation of the game at a museum in Queens, New York, examining player dispositions and high-level strategies, which we have called ‘goal alignments’.

## Related Work: Collaborative Play in Museums

There are a number of findings throughout the literature on game-based museum learning that suggests it is a generative source of informal sense-making and learning. Playful collaborative learning in museum settings allows learners to draw on outside cognitive resources (e.g. common cultural elements of social digital gameplay such as turn-taking and coaching) in order to quickly approach and apprehend material from an unfamiliar discipline [14]. The nature of games as simulations also provides engaging means of interacting with meaningful representations of tools and concepts within domains that often require highly specialized equipment and knowledges to approach [26], meaning that players can engage in interactions with content areas that are proximate to real-world instantiations of that content. Given the unique, interactive and social affordances of many museum spaces, museum exhibits allows for novel, social interfaces to allow players to move between individual and group understandings of a topic [2,18,19,23]. Museum learning can be framed as a context that is both socially situated [6,10] and allows for the distribution of cognition across individuals, spaces, and technologies [16]. Therefore, in creating playful learning experiences in museums, designers can create environments where players are collaborating to both construct meaning as a group, improve individual understandings of a domain, and engage in enjoyable experiences creating meaningful artifacts within that domain [14,19,21]. However, there are many open questions concerning how to design interactive exhibits that promote social learning experiences, as the inclusion of multiple participants can disrupt the learning feedback loop offered by single-user interactive exhibits. For example, the actions of each individual have the potential to disrupt the intentions of others [1], unequal ability to access resources can impede joint participation [13], and unclear feedback from the system can make it hard for visitors to connect effects displayed within the exhibit to their actions [22]. Moreover, visitors carry with them cultural and institutional expectations that can influence how they expect to socially interact with exhibits [20], as when they assume an exhibit that resembles a digital game must have player scores and must be structured around competition [21]. Given these design challenges, we are interested in how players interpret our aims to create collaborative experiences, and thus present the case study below as evidence of emerging findings about how specific mechanics trigger collaborative gameplay.

### Designing Rainbow Agents

Our focal domain for *Rainbow Agents* is that of computational literacy, referring to the ability of an individual to apply concepts from computation across a wide range of domains and settings [12]. Within the domain of computational literacy, we employ the specific approach of agent-based modeling (ABM): or the use of computational methods to control individual agents within a larger emergent system. ABM is attractive as an approach to computational literacy since it typically works to connect micro- and macro-level elements of a complex system through intuitive and embodied usage of computation and programming (e.g. setting the behavior of a single atom to trigger a larger chemical reaction) [29]. Games that employ ABM models, both through their design and through the social environments which develop around them, have been shown to promote computational thinking in a broad sense [5,25]. Translating ABM play to a museum-based game might seem to be a daunting prospect, but if the exhibit is structured to support a “code first” approach wherein visitors’ initial engagement involves manipulating simplified graphical programming interface, visitors can find it quite engaging [15]. Our design adopted this approach to presents learners with complex concepts from the domain of computational thinking, reduce the barrier of entry to meaningful interaction with complex computational thinking, and further, positioned our agent-based modeling game within a setting intended to support collaborative learning with the resources (both social and cognitive) of a community science museum (Figure 1).

### Competitive, Cooperative, and Collaborative Play Preliminary Findings

#### Goal Alignments

In both game design [30] and learning science theory [17] group interactions tend to be defined by three distinct orientations: competitive, cooperative, and collaborative. Competitive alignments tend to be focused on individual outcomes where success is

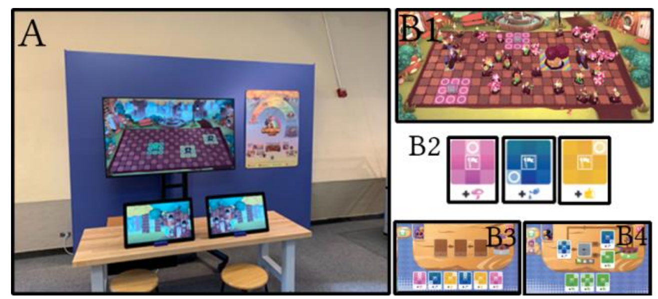


Figure 1: The game as currently installed (Label A). Players are able to approach the game as groups or individuals, since each control interface supports multi-touch interactions. Each screen manipulates a pawn in the shared garden space (B1) where players claim a part of the garden which cannot be occupied by another player. Using randomized cards from a deck (B2), players use the logic of 3 various state machines (B3 and B4, see the sidebar – Figure 2 for more detail) to move their pawn around the gamespace.


Figure 2: Players take control of three distinct agents, each of which represents a different form of ABM behavior, tapping into increasingly complex forms of computational understanding. The Hedgehog (top) allows players to construct a simple linear sequence of cards, which execute in order of left to right; The Bird (middle) gives a conditional sequence, which will look for a card type in an adjacent square, and then execute one card action if it returns true, and another if it returns false; The salamander (bottom) presents a linear sequence with three randomized conditionals, allowing players to create longer linear loops.

exclusive at the expense of others, also called negative interdependence [17,30]. By contrast, cooperative and collaborative learning have positive interdependence, where individual outcomes are tied to the success of the group.  While many use “collaborative” and “cooperative” interchangeably, they are usually distinguished by the degree of mutuality [11], e.g., where learners with a collaborative goal alignment would work in concert towards a single goal, learners with a cooperative goal might be working in parallel towards different (complementary) goals. In museums, these boundaries get blurred further - visitors can and do shift in and out of more collaborative modes of interaction, bringing with them ideas and knowledge gained via more individualistic phases of interaction [27], as the following analysis will reveal.

**Shifting Alignments in the Beta Implementation:**
*Competitive:* As the group approached the game the players separated into two dyad groups (Player A & B; Player C & D – Figure 3). As the two dyads started to make sense of the game, they also tended to phrase the initial sensemaking process as a ‘race’, with each pair attempting to achieve the negatively interdependent goal-alignment of being the ‘first’ to figure the game out. Throughout this first phase of gameplay the two groups tend to move back and forth between sensemaking statements (stating potential hypotheses about the game’s mechanics) while also engaging in similar competitive banter back and forth, for example after the above exchange there is an argument about which group ‘got it right’ first, with Player D saying, "We also got it right over here… More quickly than you."

*Cooperative:* However, after a brief clarifying conversation with the facilitator, the players begin to work cooperatively: with individual players directing the action of others. For example, Player A has a realization about the color coding of cards, saying, "So if we place [these cards] over here, we get mushrooms..." B asks a clarifying question to that statement, "Wait, how do you know you got to place them over there?" A clarifies his reasoning, "Because [the color of the cards and chest] match. Perfectly." B clarifies again, "Because they’re purple?" and A agrees, further giving B an imperative command to execute on the screen, "Yeah. They match. Okay… so you just put purple in, and it’ll work. Like… this one will go here [pointing]." C and D are developing their own understandings of the game.

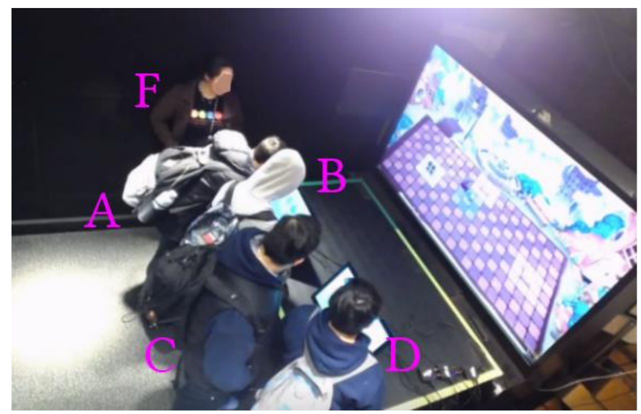


Figure 3: Video capture of the data that we drew our case analysis from. Players are referred to by the letter labels.

**Core Mechanics:**

**Shared Gamespace** (see label B1 in Figure 1) - Players place their agent onto a shared field, modeled after the concept of a community garden. Within this space players must move their pawn while keeping your fellow player in mind, promoting the idea computational concept of mutual exclusion.

**Common Interfaces** - Players have access to the same types of cards (B4), however each player pawn receives random deals that are designed to distribute card types between the two pawns in a diverse fashion.

**Multi-Touch Controllers (B2 & B3)** - Each player interface is multi-touch, and allows for smaller sub-groups of players to contribute to the programming of each agent.

**Distinct Agents** - There are three types of agent (see above sidebar), each of which has its own computational possibilities within the game. This introduces players to the concept of a 'state machine'.

For example, C and D are working in a different part of the shared garden. C seems less enthusiastic, but D is talking excitedly about his strategy. He points to the main screen, saying, "Ooooh, we need to get the [avatar] to go over there [pointing]." C shrugs, and unenthusiastically says, "Ok…"

*Collaborative:* As the players begin to grasp the game and experience small successes, they start to work collaboratively as well - breaking out of the dyad structure, and moving into a formation where all four players are actively working across both screens to communicate and formulate strategies. An example comes as Player D first realizes the plant wilting mechanic, saying, "[pointing at the main screen] Look, yo, the plants are dying out!" Player B looks up, and with alarm says, "Wait, the plants are dying!? … Wait, what does that mean?" Player D points again, saying, "Look, they're turning gray. … Go back to the other animals [meaning the simplest state agent] since they're dying out. Look, everything is turning gray." Both dyads work towards maintaining the garden, and after a few minutes their efforts pay off as they figure out the mechanism to unlock chests, triggering the collaborative slider mechanic, with all players providing input to the group description such as "You guys want to place it on a chest? One higher…" and, "No, one lower." Player A addresses the main group, saying, "I'll go there and help them out," and B connects with that, saying "So, it's a team effort, right?"

## Conclusions and Next Steps:

In the vignette described above we can see three primary shifts among our players. Eventually these four players do approach the game as it was designed, with a collaborative goal alignment. However, both the competitive and cooperative goal alignments have their own place in the sense-making process of the four boys.

In our emerging model (see Figure 4), **distinct agents** controlled by **multitouch controllers** play a key role in setting up players to assume **competitive** roles presenting the expectation that they are engaging in similar tasks and need to outperform the other. The competitive behavior exhibited in the above vignette shows an initial disposition among these players to *be the first* to solve the problem they face. Although the game is not designed to be competitive, an early competitive goal alignment seems to have allowed players to build independent understandings of the agents as *state machines*. Importantly, although competition may seem at odds with the goals of our game, these players still resulted in an extremely productive understanding of the ABM nature of *Rainbow Agents* for the players in the above vignette. **Common resources** within the **multiple controllers** was key in enabling **cooperative sensemaking** across the teams - insights about using cards matching plant colors could be understood, tested, and applied across both dyads' **distinct agents** since they were using similar resources. Thus, as with cooperative learning, the two dyads pursued different sub-elements of the same general goal (seeding and watering plants). The **shared gamespace** eventually played a critical role in enabling **collaborative goal and task sharing** across the players' agents. When the players had an adequately shared understanding of the game, they were able to coordinate on shared goals (like saving certain plants) using separate agents acting in parallel, but with a shared purpose across the group of four rather than as a pair of dyads. This activity gave them an embodied access to the computational concepts of *parallelism*, as well as *agent-based modeling* - different agents acting in parallel can transform the shared object (the game's garden) simultaneously, and when engaging with independent as well as shared goals, leads to varieties of system-level behaviors.

The beta-test implementation described above revealed that even when an exhibit is intended to be collaborative, visitors may rely on different design features at different times in order to support different goal alignments, and shifts between them. Further, it illustrates that an initial, competitive goal alignment might actually be a useful step in facilitating both learners' understanding of the game mechanics, and their later collaborative interactions - and so designers may be wise to create designs that do not preclude competitive goal alignments. We have deployed the current version of the game to science museums in both Queens, New York and Berkeley ,California, and are currently collecting data through log files that record all significant interactions in the game, anonymous audio and video records timestamped to gameplay sessions, facilitator field notes and dispositional surveys to players within our targeted age demographic, and screen captures of the game's three screens. As data-collection with the game begins in full we have drawn from our design goals and early findings to develop three primary design questions to interrogate our data: 1) How do players from varying backgrounds enact their own shifts in goal alignments? 2) How do elements of the game developed for computational literacy evidence themselves in logfiles and qualitative data? 3) How do further manipulations to resource availability and distribution of the game (e.g. starting hands, treasure spawn rates, etc.) influence both learning outcomes and collaborative play?

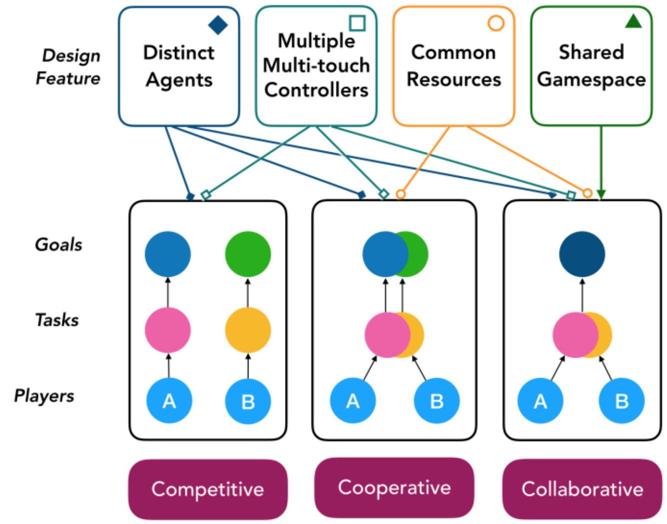


Figure 4: Our emerging model of gameplay in Rainbow Agents, framed in terms of gameplay mechanics and goal-alignments observed in the above case study.

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