Designing and Developing Interactive Narratives for Collaborative Problem-Based Learning

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Abstract. Narrative and collaboration are two core features of rich interactive learning. Narrative-centered learning environments offer significant potential for supporting student learning. By contextualizing learning within interactive narratives, these environments leverage students' innate facilities for developing understandings through stories. Computer-supported collaborative learning environments offer students rich, collaborative learning experiences in which small groups of students engage in constructing artifacts, addressing disciplinary challenges, and solving problems. Narrative and collaboration have distinct affordances for learning, but combining them poses significant challenges. In this paper, we present initial work on solving this problem by introducing collaborative narrative-centered learning environments. These environments will enable small groups of students to collaboratively solve problems in rich multi-participant storyworlds. We propose a novel framework for designing and developing these environments, which we are using to create a collaborative narrative-centered learning environment for middle school ecosystems education. In the learning environment, students work on problem-solving scenarios centered on how to support optimal fish health in aquatic environments. Results from pilot testing the learning environment with 45 students suggest it supports the creation of engaging and effective collaborative narrative-centered learning experiences.

Keywords: Narrative-centered learning, Collaborative learning.

1 Introduction

Recent years have seen significant growth in research on the role of narrative and collaboration in education. Narrative-centered learning environments contextualize learning within interactive narratives in which students actively participate in engaging story-based problem solving [1,2]. These environments encourage students' active participation in learning, critical thinking, and analysis. Meanwhile, computer-supported collaborative learning environments offer students inquiry experiences that are deeply collaborative [3]. These environments engage students in investigating complex ill-structured problems, making use of authoritative resources, and constructing informed explanations. Leveraging the affordances of both narrative-centered learning environments and computer-supported collaborative learning environments offers significant potential.

By integrating narrative-centered learning with collaborative learning, *collaborative narrative-centered learning environments* will enable small groups of students to collaboratively solve problems in rich multi-participant storyworlds. As opposed to traditional narrative-centered learning environments, in collaborative narrative-centered learning environments, students work in groups solving motivating problem-based learning scenarios that feature compelling plots, engaging characters, and inviting settings. These environments will dynamically generate narratives to be interactively experienced by a group of participants. (We use the term "participant" to emphasize the active role played by students experiencing and affecting the narrative that is unfolding in the multi-participant interactive environment.) Here, computational models of narrative must craft global story arcs and dynamically direct storyworld events to create the most effective collective story-centric learning experience for all of the participants. For collaborative narrative-centered learning environments, these computations entail dynamically selecting and arranging plot elements that will engender group-based problem-solving activities so that participants can together achieve the resolution of the narrative, while developing flexible knowledge, critical reasoning skills, and collaboration skills.

2 Background

2.1 Narrative-Centered Learning

Computational models of narrative can serve as the foundation for learning environments that provide effective story-centered pedagogy that is both meaningful and motivated [4-8]. In narrative-centered learning environments, learning occurs in the context of interactive narratives [9-11]. Such learning environments leverage the power of dynamically generated narrative to create learning experiences that are both effective and engaging. Drawing on intelligent tutoring systems, intelligent virtual agents, and serious games, narrative-centered learning environments offer the promise of adaptive, situated learning experiences that are highly interactive and engaging for students. Narrative-centered learning environments have been investigated in a broad range of educational domains, including anti-bullying education [4], health intervention education [12], social issues [13], computational thinking [14], and science learning [9,15]. In addition to education, narrative-centered learning environments have also been used effectively in training [16-18]. While significant progress is being made on narrative-centered learning environments, most of the work to date has focused primarily on single-learner scenarios.

2.2 Collaborative Learning

Contemporary approaches to inquiry learning are deeply collaborative [3]. Collaborative inquiry involves small groups of students engaging in constructing artifacts, addressing disciplinary challenges, and solving problems. These approaches rely on scaffolded student engagement, including different forms of learning cycles that help provide norms, routines, and teacher guidance [19,20]. Problem-based learning (PBL) is an effective approach to enabling collaborative inquiry that challenges students with investigating and resolving complex, ill-defined problems [21,22]. In PBL, students engage in self-directed learning as they collaboratively solve problems while co-constructing flexible knowledge through small group discussions and negotiations [22]. Story-centric scenarios often serve as an effective approach for structuring the problems that lie at the heart of problem-based learning for students [23]. Although originally developed as an instructional model for medical schools, there is significant interest in applying PBL within primary and secondary education [24], including science classrooms [23]. Although progress is being made to realize the potential of problem-based learning through computer-supported collaborative learning environments, limited work has explored the unique opportunity provided by the rich, dynamic problem contexts of narrative-centered learning to support deep collaborative inquiry at the classroom scale.

3 Designing Collaborative Interactive Narratives

Collaborative narrative-centered learning environments extend educational narratives into the social arena and call for the creation of *computational models of collaborative narrative generation*. Rather than generating narratives for a single participant, computational models of collaborative narrative generation create shared, collective narrative experiences to be interactively experienced by a group of participants [25-27]. In contrast to multiplayer online games in which a loosely formed sense of narrative may emerge from sandbox-style interactions or completed quests, computational models of collaborative narrative generation are concerned with explicitly reasoning about narratological elements (fabula, sjužet, and medium) to create engaging narrative experiences for groups of participants. The work presented in this paper focuses on computational models of collaborative narratives with an emphasis on collaborative learning in which students cooperate to solve ill-structured problems. Our work targets the generation of narratives for small multi-participant groups consistent with problem-based learning. Computational models of collaborative narrative generation must address two sets of design requirements: those stemming from interactive narrative generation, and those stemming from the multi-participant nature of collaborative narratives. Each of these is discussed in turn.

Computational models of interactive narrative generation construct stories in which an audience member plays an active role. In addition to crafting narratives that have many of the properties of traditional stories such as conflict, compelling characters, plot-driven storylines, and crisis decision points, computational models of interactive narrative should create narratives that exhibit three properties: 1) *participant agency*, which imparts the perception of control to the participant with respect to the short-term and long-term impact of her actions on the story [28,29]; 2) *believable characters*, in which the participant's interactions with "non-player" characters are contextualized in the narrative's plot and setting [4,30]; and 3) *participant-tailored experiences*, in which plot elements and character behaviors are customized to the individual participant [31,32].

In addition to the requirements noted above for interactive narrative, computational models of collaborative narrative generation should address the following requirements. First, the models should support collaboration-centered plot generation, in which the narrative generator creates plot lines that require cooperative actions on the part of the participants. For example, they should introduce plot points requiring participants to devise plans leading to the achievement of a common goal, and they should encourage communication among participants. Second, the models should support role-based participant-character interactions. Endowing characters with specific expertise and abilities is an oft-used literary device from traditional narratives, and it can be effectively leveraged in collaborative narratives for both participant characters and synthetic characters (e.g., virtual agents). Third, the models should create stories that maximize the utility of the resulting narratives. In addition to being engaging for a single individual participant, collaborative narratives should be engaging for the group as a whole.

Our approach to organizing computational models of collaborative narrative generation employs the jigsaw methodology to create multi-participant groups for collaborative problem-based learning. In *jigsaw-based problem solving*, students become experts on different aspects of the problem under investigation and then share what they have learned with group members [33]. Effective collaborative work depends upon the presence of positive interdependence between participants, thereby requiring students to interact and rely upon contributions of others [34]. Most effective collaboration occurs when group members have both resource and goal interdependence. Jigsaw approaches used in science classrooms have led to increases in affective outcomes [35], and Aronson and Bridgeman (1979) argue that the jigsaw methodology reduces classroom competition and creates an environment that leads to goal attainment [36]. Jigsaw-based problem solving offers a practical and effective approach to organizing the design of collaborative problem-based learning narratives.

4 Developing Collaborative Interactive Narratives

While promising, integrating interactive narrative and collaboration to create effective group learning experiences poses significant challenges. To this end, we have designed StoryLoom, a rapid prototyping tool for creating interactive narratives that enable students to work together to solve problem-based learning scenarios, while allowing researchers to investigate collaborative learning within the classroom.

4.1 Architecture

The StoryLoom architecture defines key components of a collaborative interactive narrative that represent distinct groups of functionality and resources (Figure 1). The primary purpose of StoryLoom is to provide a blueprint for creating engaging interactive narratives that support effective group learning. To this end, the architecture defines two types of resources that when combined represent the narrative experienced by a group of students: *World Resources* and *Story Resources*.

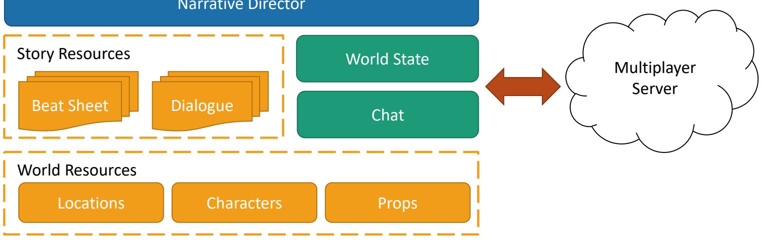

Fig. 1. StoryLoom architecture.

World Resources are the building blocks for the storyworld that the students will experience while interacting with StoryLoom: *Locations*, *Characters*, and *Props*. These resources represent the physical manifestation of the narrative. These are the objects that the students will see, hear, and interact with as they are transported into the storyworld. The Story Resources define how the World Resources interact with each other and with the students as they progress through the narrative. Story Resources are composed of *Dialogue* and *Beat Sheet* resources. Dialogue resources represent the conversations, narration, and dialogue choices presented to the students as they interact with characters, manipulate props, and visit locations within the storyworld. A Beat Sheet resource represents a complete story within the narrative environment from a particular student's perspective organized around the jigsaw methodology with the student becoming an expert on some aspect of the story. A story beat is an event within the narrative where something changes and the story advances [37]. For example, a young boy learns he is a wizard after receiving an acceptance letter to wizarding school. The Beat Sheet resource, as defined in the StoryLoom architecture, is a collection of story beats that represent the entire narrative experienced by a student. A story may contain multiple character roles that can be assumed by students. Each beat sheet represents a different narrative experience within a larger collaborative story, and thus there may be multiple beat sheets in a story, each one describing the story from a particular student's perspective.

Another key requirement of StoryLoom is to allow students to interact and collaborate within the storyworld as they experience the interactive narrative. This functionality is represented by three components within the architecture: *Multiplayer Server*, *World State*, and *Chat*. The Multiplayer Server is responsible for providing a real-time communication channel between each interactive story client that is participating in a shared narrative experience (Figure 2). The Multiplayer Server allows multiple students to interact over a network connection. It also allows an optional tutor, perhaps a human serving in the role of a wizard within a Wizard-of-Oz data collection or an intelligent tutoring system, to participate in the learning experience by providing content and collaboration scaffolding as the students work together to solve the problem-based learning scenario. The World State component represents the functionality and data that must be replicated across all of the interactive story clients and the optional *Tutor Control Panel* in order to create a consistent and shared virtual world and narrative experience for all the students (Figure 2). For example, if a student places a sticky note on a whiteboard in the virtual world, the same action must be replicated to all of the other students' interactive story clients. Lastly, the Chat component represents the functionality that allows students as well as the tutor to communicate across the network in real-time. This functionality is crucial for collaborative problem solving as students share what they have learned and discuss possible solutions to the problem scenario within the context of the interactive narrative.

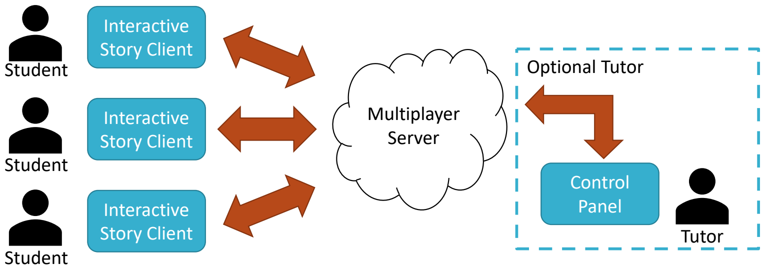

Fig. 2. Interactive story clients collaborating with a human tutor.

The *Narrative Director* is a central component within the StoryLoom architecture that is responsible for orchestrating the interactions of all the other components within the interactive story clients to generate a collaborative, problem-based learning experience (Figure 1). The Narrative Director loads narrative-specific Story and World Resources based on the role assumed by the student within the larger shared narrative. For example, a student may have assumed the role of a toxicologist in a team of scientists who have been asked to determine why farm animals are getting sick. The toxicologist Beat Sheet would contain individual beats that define a unique narrative in which the student (acting as the toxicologist) visits the farm, takes water samples from the pond, and then discovers that the water is contaminated with hazardous chemicals. This narrative experience will be unique to the student playing the toxicologist role. Likewise, the other students will experience their own unique narratives based on their roles as they gather evidence to be shared and discussed as part of the collaborative problem-solving learning experience within StoryLoom. For example, two students playing the roles of a toxicologist and botanist might progress through a simple narrative in which each student experiences unique story beats that provide evidence and insights that are shared during collaboration sessions where they discuss and negotiate as they work together to determine why the farm animals are getting sick (Figure 3).

The *Camera* and *User Interface* components in the architecture represent how the narrative is conveyed to the student, while the *User Input* component represents how the student interacts with the narrative. The interactive story client might be implemented using a high-fidelity 3D game engine, which would produce immersive experiences in which students have the freedom to travel between realistically rendered locations and interact with lifelike characters as they experience the narrative. In this situation, the World Resources in the architecture would consist of 3D models, animations, and audio.

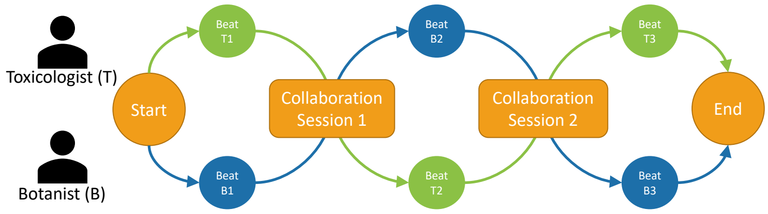

Fig. 3. Two-student progression through a shared collaborative learning experience.

4.2 Implementation

The StoryLoom architecture presented above was used in the design and development of a 2D visual novel-style collaborative narrative-centered learning environment. The learning environment was developed using an agile development process in which the software was iteratively designed, implemented, and reviewed. This particular implementation of StoryLoom supports rapid prototyping and deployment of 2D interactive narratives into classrooms. In this implementation, the Camera, User Interface, and User Input components were implemented using the Unity game engine. The Unity game engine is capable of rendering 3D environments and characters. However, we decided to create a 2D narrative experience to simplify art creation, while we focused our development efforts on refining the narrative and collaboration-specific functionalities. The Unity game engine is cross-platform and enables the learning environment to be deployed on a wide variety of platforms such as Windows, macOS, Android, iOS, and Chromebooks.

This version of StoryLoom presents the storyworld to students as 2D representations of locations, characters, and props. Because students can choose to travel between locations, converse with characters, interact with props, and collect information as they progress through the problem-solving scenario, they are active participants within the narrative. For example, a student could be asked by a character in the learning environment to travel to a fish hatchery and measure the dissolved oxygen levels in a water tank as the student attempts to determine why the fish have become sick. This implementation of StoryLoom includes text-based chat that students can use at any time during the narrative to communicate with one another. In addition, a human tutor can also participate in the conversation to provide content or collaboration scaffolding.

This 2D version of StoryLoom provides a flexible framework for quickly developing and evaluating interactive narratives by allowing non-technical authors to create story beats in a Google Sheet and author dialogue in Google Documents. These documents are imported into the system as Beat Sheet and Dialogue resources that are combined with the 2D representations of locations, characters, and props to produce an interactive narrative. Using Google Docs as an authoring tool has several significant advantages for authors: 1) familiar and feature-rich word processor, 2) collaborative authoring, and 3) revision tracking and revert capability, and 4) readily available. These features allow content to be authored and easily revised, thus, enabling a tight iterative loop to quickly refine the narrative experience.

This version of STORYLOOM fully supports the creation of jigsaw-based narratives where students acquire expert knowledge as they experience their own unique stories. This acquired knowledge can then be shared with their group through collaboration as they work together to solve a problem-based learning scenario. When using this version of STORYLOOM to create a collaborative, narrative learning experience, the following high-level steps are used to structure the jigsaw-based narrative: 1) Create an overarching narrative that features the problem-based learning scenario, 2) Identify possible solutions including knowledge required to solve the problem, 3) Create individual narratives that correspond to roles within the larger overarching narrative wherein students acquire knowledge, 4) Define story beats in a Google Sheet that represent the significant events that move each individual narrative forward, 5) Identify characters and author dialogue in a Google Document for narration and conversation associated with the story beats (such interactions reveal expert knowledge to the students), 6) Create story beats that represent collaboration points in the overarching narrative, 7) Identify all of the locations, characters, and props necessary to tell the story and create art assets for them. The artifacts from the previous steps can then be combined with STORYLOOM to create a deployable learning environment. Creating a collaborative interactive narrative is a creative endeavor and will likely require several passes through the above steps.

5 CRYSTAL ISLAND: ECOJOURNEYS Testbed

To investigate how interactive narrative and collaboration can be combined to yield effective small group learning experiences in the classroom, we created CRYSTAL ISLAND: ECOJOURNEYS to serve as a testbed for prototyping a collaborative narrative-centered learning environment to be deployed in classroom studies (Figure 4). Chromebooks were selected as the lead development platform due to their availability for use at our partner schools as well as their widespread adoption by schools throughout the United States. ECOJOURNEYS was developed using the 2D version of STORYLOOM described above. Locations, characters, and props are presented to students as 2D assets. The learning environment's look and feel closely resembles a genre of video games referred to as "visual novels".

The interactive narrative that was authored for ECOJOURNEYS tells the story of four students who are visiting Buglas Island in the Philippines as part of a cultural exchange program. While on the island, the students learn from local farmers that the fish in their fish farms are getting sick. Since fish farming is critical to the island economy, the local stakeholders ask the students for help in investigating why the fish are getting sick. The students' relationship with the local stakeholders follows an apprentice-based model [38]. The stakeholders provide the expertise and insight critical to solving the problem. As newcomers to the island, the students are tasked with "pitching in," to help with the investigation. The interactive narrative reveals a complex problem scenario that four students are asked to solve together as a group. Each student will experience a unique narrative within the context of the larger story as they visit different locations, have conversations with characters, and interact with props as they help solve the mystery.

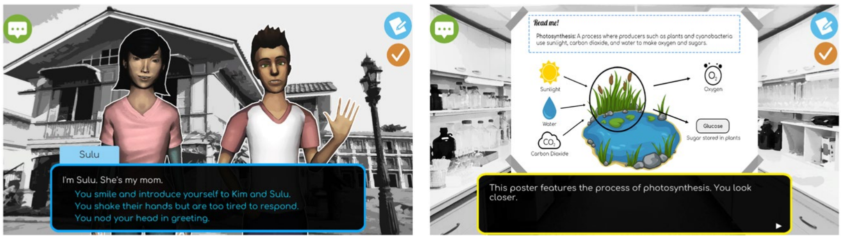

Fig. 4. Interacting with characters and props in CRYSTAL ISLAND: ECOJOURNEYS.

In addition to text-based chat, ECOJOURNEYS includes a virtual whiteboard (Figure 5) to support collaboration and the problem-based learning inquiry cycle [39]. During collaboration sessions within the context of the interactive narrative, students are asked to go to a virtual conference room in the storyworld. There, students place sticky notes on the virtual whiteboard. These notes were collected during students' unique explorations and contain information related to the aquatic problem.

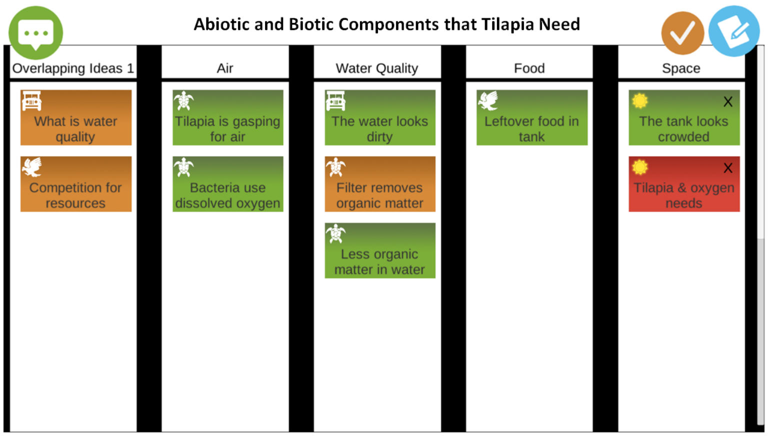

Fig. 5. Virtual whiteboard used by students during collaboration points.

The sticky notes can be associated with specific topics that help students support or rule out hypotheses. As students share their notes at the whiteboard, they discuss their findings and attempt to arrive at a hypothesis that is both supported by the evidence and that explains why the fish are getting sick. The virtual whiteboard was designed to support the following collaborative interactions between small groups of students: 1) sharing information, 2) selecting information to be used as evidence, and 3) evaluating whether evidence supports, does not support, or might support a specific hypothesis. Furthermore, to support sensemaking, students can vote on a sticky note which will cause it to change color to indicate whether students agree (green) or disagree (red) that the information on the note supports the hypothesis represented by the column. An orange sticky note indicates that not all the students have voted on whether the note supports a hypothesis or not. If students disagree on the placement of a sticky note, they must negotiate using the text-based chat to resolve their disagreement. This provides students with sense-making agency, since they are allowed the freedom to make mistakes as they collaborate and reason about the evidence and how it relates to the hypotheses.

Because ECOJOURNEYS is built upon STORYLOOM, the team was able to rapidly create a collaborative narrative-centered learning environment that was ready for deployment into the classroom. This left additional time for the team to focus on two elements that are key to the PBL inquiry cycle: the interactive narrative and scaffolded collaboration. STORYLOOM's Google Docs-based authoring allowed the four narratives that represent each student's role in the overarching narrative to be quickly written and easily refined through rapid iteration. This allowed the creation of the jigsaw-based problem scenario where students learn from experts as they experience the interactive narrative by talking to characters and collecting evidence. Likewise, STORYLOOM's data replication functionalities allowed for the creation of the shared virtual whiteboard, which, along with text-based chat, allowed students to share what they learned with group members. Figure 6 depicts a student's narrative experience as they collect jigsaw-based information through the interactive narrative and collaborate with the group through the virtual whiteboard. To ensure that students have access to critical information required to solve the mystery, key jigsaw-based information was provided to at least two students in their narrative experiences (i.e., similar facts or observations). Thus, the information was more likely to be discovered and shared by students during their collaboration.

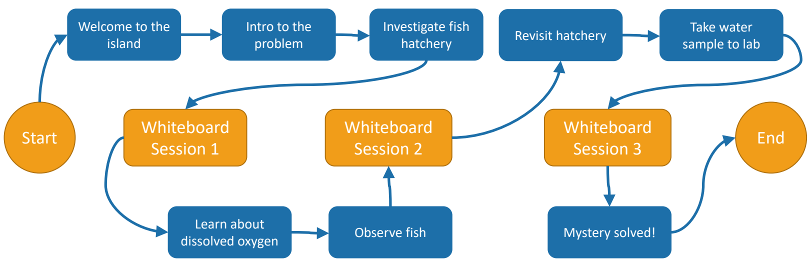

Fig. 6. Story beats and collaboration points of student's unique narrative experience.

Another important feature of STORYLOOM that was utilized in ECOJOURNEYS was the capability to have an expert human tutor join the group of four students in the chat and virtual whiteboard sessions. This facilitator provided scaffolding for both collaboration and inquiry-based thinking. The facilitator was also responsible for checking the students' work in the whiteboard sessions before allowing the students to continue on through the narrative. If the virtual whiteboard contained hypotheses that were not correctly supported (or disproved) by the evidence, the facilitator could provide hints or suggest approaches to the students to resolve disagreements. Once the facilitator was convinced that the students had successfully completed a whiteboard session, she would use the STORYLOOM Control Panel to allow the students to exit the whiteboard and continue through the narrative.

6 Pilot Study

To evaluate the effectiveness of ECOJOURNEYS, we conducted a pilot study to understand if it supported productive collaboration and effective learning.

6.1 Participants and Procedure

A total of 11 groups of students (N=45, 22 females, 23 males) ages 11 to 12 from the rural midwest in the United States participated in the classroom study for a total of nine 55-minute sessions. Students worked in groups of four (except for one group of five). Each group was assigned a facilitator who provided prompts focused on supporting collaboration and inquiry thinking. On the first day of the study, students took a pre-test and were introduced to their groups. They also generated a group contract that allowed them to dictate the norms for collaborative inquiry learning that they wished to follow. On the second day, students started playing ECOJOURNEYS. Throughout the sessions, students collaborated with their group members via text chat and at the virtual whiteboard. Students evaluated the data that each student gathered and discussed possible explanations to the problem scenario. On the last day, students created an explanation as to why the fish were sick and took a post-test.

6.2 Data and Analysis

The pre-post test focused on ecosystem concepts, specifically the relationship between biotic and abiotic components and the impact that these components have on populations in an ecosystem. Students also took a survey from the Adaptive Instrument for Regulation of Emotions survey [40]. Log data of students' chat and interaction within the learning environment were recorded and stored on a remote server. Group chat log data was coded according to accountable talk and PBL facilitation moves [41,42]. Each conversational turn in the chat log was coded for one of the following turn-taking codes: *Collaboration* (five sub-codes), *Rigorous Thinking* (ten sub-codes), *Facilitation* (six sub-codes), and *Content* (eight sub-codes). Collaboration codes refer to utterances that focus on coordinating, goals, and content understanding whereas Rigorous Thinking codes highlight students' argumentation moves. Utterances made by facilitators were coded separately from students' talk (i.e., Facilitation) and all utterances were coded for the Content of the talk.

6.3 Results

A mixed ANOVA test with groups as between-subjects and time as within-subjects factor indicated a main effect of time. Students scored significantly better on their post-tests, $F(1, 49) = 17.919$, $p < .001$ (pre-test mean = 13.6, SD = 3.7; post-test mean = 15.8, SD = 3.7), indicating that students improved their ecosystem concept knowledge overall. Analysis of group chat data revealed that there was a positive strong relationship between the total Collaboration and students' Rigorous Thinking codes, $r(9) = .78$, $p = .004$ and a moderate relationship between the total Facilitation and Rigorous Thinking codes, $r(9) = .71$, $p = .015$. These results suggest that productive collaboration among students are critical in supporting robust argumentation. Students also remained engaged in the game, with 66% of student utterances coded for productive discussions.

7 Conclusion and Future Work

Collaborative narrative-centered learning environments, which integrate narrative-centered learning with collaborative learning, offer significant promise for creating effective and engaging learning experiences. These environments enable small groups of students to actively participate in collaborative problem solving featuring compelling plots, engaging characters, and inviting settings. In this paper, we have presented STORYLOOM, a novel framework for designing and developing collaborative narrative-centered learning environments. Using the framework, we developed a prototype learning environment, CRYSTAL ISLAND: ECOJOURNEYS. A classroom study with middle school students indicates that interactions with CRYSTAL ISLAND: ECOJOURNEYS yielded improved learning outcomes and evidence of productive collaboration. These results suggest that STORYLOOM holds promise for creating effective and engaging group-based narrative learning experiences.

Two directions for future work are particularly promising. First, since scaffolding is critical for supporting student teams, developing automated models to provide support during students' problem solving is key. In our pilot study, a human facilitator provided guidance via a text chat interface to help orchestrate student interactions. Devising adaptive conversational agents that use natural language dialogue capabilities to provide automated scaffolding functionalities for collaborative narrative-centered learning environments is a promising direction. Second, investigating computational models of collaborative narrative generation that leverage artificial intelligence-based techniques offers significant promise for creating learning experiences that feature dynamic collaboration-centered plots and adaptable role-based interactions that adapt to students' desires and behaviors.

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