Designing an adaptive collaborative problem-solving system with expanded evidence-centered design

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Abstract: In this paper, we detail the design of an adaptive collaborative problem-solving system in a game-based inquiry environment. We apply the expanded evidence-centered design (e-ECD) framework, an approach that specifies the relationship between learning and assessment. A key assumption of the classic ECD framework is that assessments capture student competencies which are 'fixed' during the time of the assessment. However, in our game-based inquiry environment the system responds to student behaviors by scaffolding student learning. This means that there is a desired *change* in learner competencies as students respond to the computer-based prompts. Drawing on the e-ECD framework, we articulate this model of change in our environment. We draw on the zone of proximal development and learning progressions to articulate student proficiencies, task, and evidence models related to the change model.

Introduction

A key benefit of game-based inquiry environments is their ability to embed assessments as part of students' real-time interactions (Kim & Shute, 2015). To support the design of game-based assessments in computer-supported collaborative learning (CSCL) environments, evidence-centered design helps practitioners and researchers attend to evidentiary arguments, wherein claims about what students know can be inferred from what they do (Mislevy et al., 2014). The framework consists of three core components: (1) the *proficiency model* or competencies being measured, (2) the *evidence model* or the observable variables and how they are measured, and (3) the *task model*, or activities and work products that elicit evidence of learning. A key assumption of the ECD framework is that assessments capture student competencies which are 'fixed' during the time of the test. On the other hand, game-based inquiry environments respond to student behaviors by scaffolding student learning. This means that there is a desired *change* in learner competencies in these learning systems as students respond to the computer-based prompts.

Recently, Arieli-Attali et al. (2019) proposed an expanded evidence-centered design (e-ECD) framework, an approach that specifies the relationship between learning and assessment in learning systems. We draw on the zone of proximal development to articulate the relationship between collaborative inquiry learning and assessment in our game-based inquiry environment, CRYSTAL ISLAND: ECOJOURNEYS (Saleh et al., 2020; Vygotsky, 1978). In this paper, we articulate our design of an adaptive collaborative problem-solving system that first diagnoses students' current competencies and then provides scaffolds for what learners should do (Rosen et al., 2021). First, we describe the zone of proximal development, and then the change elements of the e-ECD framework. Finally, we unpack the student, evidence, and task models in CRYSTAL ISLAND: ECOJOURNEYS and discuss the implications of our work for game-based learning and assessment. Given the need to productively capture student data for the purpose of assessing and understanding students' learning, this design paper focuses on the question, how can we design learning tasks and associated scaffolds to support collaborative inquiry outcomes?

Zone of proximal development

The zone of proximal development (ZPD) is the difference between how a learner performs independently and how the learner performs with the support of a "more knowledgeable other" (Vygotsky, 1978). The ZPD was theorized as a construct for assessment and to clarify the association between learning and development. Thus, individual learning involves an appropriation of collective or shared social practices (Rogoff, 1995). This appropriation is influenced by students' interpersonal communication and their interactions with instructional supports, or scaffolds. In prior work, we detailed how accountable talk functioned as a soft scaffold in tandem with hard scaffolds in the game-based learning environment to support collaborative inquiry learning (Saleh et al., 2020). This work extends prior research and articulates the design of scaffolds in our environment that adaptively support student learning.

CRYSTAL ISLAND: ECOJOURNEYS

CRYSTAL ISLAND: ECOJOURNEYS is a collaborative game-based learning environment where students work in groups of three or four to solve an ill-defined aquatic problem. Within the game, students are introduced to what we refer to the TIDE inquiry cycle, a conceptual representation of scientific inquiry processes and is based on collaborative actions that are central to science inquiry learning (Saleh et al., 2020). This consists of *Talking* to their peers, *Investigating* the problem, *Deducing* patterns from the data, and *Explaining* why the problem is occurring. As students engage in each phase, the arrow in the representation changes to a different color. To facilitate engagement in the TIDE inquiry cycle, we designed six core in-game activities centered on (1) conversations with in-game characters, (2) collecting information using a structured note-taking tool, (3) a video resource tool that shares science content, (4) a Deduce! tool that supports collaborative analysis, (5) a digital problem-based learning whiteboard tool that supports collaborative explanation, and (6) an in-game chat tool for students to interact with another.

Student proficiency model

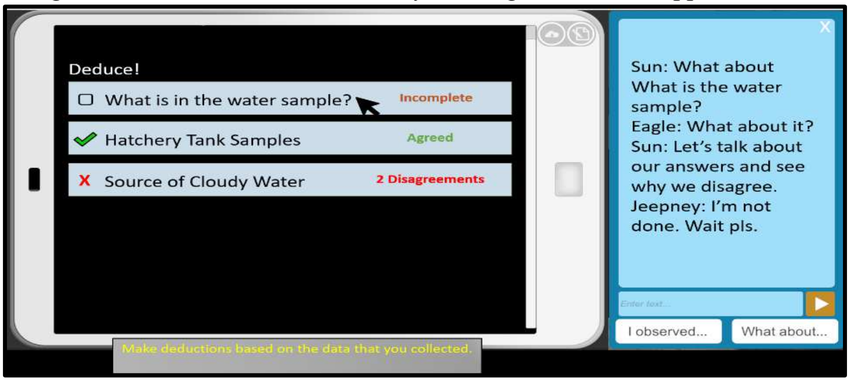
In the original ECD framework, the proficiency model is characterized by identifying focal knowledge skills and ability (KSAs) and associated knowledge skills and abilities. KSAs are the targets of assessment and need to be outlined explicitly. In a typical assessment, these proficiencies are assumed to be unchanging, since the student is taking a test at a given time. However, in learning environments, students' proficiencies change because of their interactions with tools and scaffolds embedded in the system (i.e., the KSA-change model.) Thus, it is necessary to articulate the KSA-change model or the learning processes that need to occur to achieve the desired proficiencies. To illustrate the relationship between students' change-model and their desired proficiencies, we draw on learning progressions for collaborative problem solving (OECD, 2017; Rosen et al., 2021). Learning progressions are frameworks that highlight students' increasing proficiency in particular disciplines and practices. Representations of students' learning performances are denoted as progress variables, which demonstrate improvement as students engage in a specified task, be it curricular instruction or assessment (Kennedy & Wilson, 2007). Progress variables have upper and lower anchors that illustrate how students shift from initial to more sophisticated competencies. These anchors define the learning layer, or the KSA-change model as students engage in CRYSTAL ISLAND: ECOJOURNEYS. The KSA-change model describes the sequences of knowledge processes necessary to lead student to the desired student proficiencies.

Due to space constraints, we focus on three collaborative competencies in our learning environment: (1) sharing resources and ideas, (2) planning actions to solve the problem, and (3) organizing group work effectively. Drawing on a learning progression allowed us to consider students' initial proficiencies and the sequences that lead up to their best of their capabilities. Consider the initial anchor for collaborative problem solving. At this level, students can complete tasks with low complexity and limited collaboration. Students share information and make plans but require prompting. These students also do not make proposals of their own, tend to agree on proposals made by others, and focus more on their individual role within the group. To identify learning in the KSA-change, it is crucial to articulate processes that support students in progressing to higher levels in the progression. Drawing on the ZPD, we assume that learning can occur with the support of material and social interactions and provide scaffolds across the system and teacher. These prompts are aligned to the desired competencies (i.e., students encouraged to share or make plans). For example, if the system detects that students have not engaged in level 1 proficiencies, it will first deliver scaffolds in the form of group-level prompts. These prompts will ask students to check in with their peers and ask for perspectives on the problem. If the desired action is still not detected, the teacher will be alerted. Teachers will have information about the types of prompts provided. It is expected that students who are at a higher proficiency level require fewer scaffolds, or the scaffolds can be faded out.

Instantiating the proficiencies in the task-support model

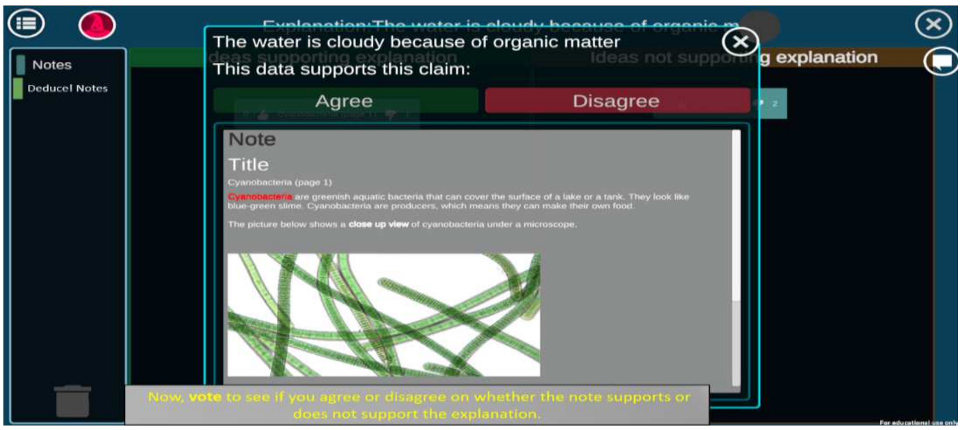
In the original ECD framework, the task model must clearly articulate its relationship to the student proficiency model so that we can consider the reliability and validity of the tasks. The task model for collaborative problem solving is tied to students' engagement in the TIDE inquiry cycle and with in-game tools. Here, we focus on the task-support model, or the scaffolds provided to support student shifts along their learning progression. As students engage in the Investigation phase, they must talk to in-game characters. As part of their investigations, we expect that some students will spontaneously talk and share information with their group members. To support learning, the task-support model will encourage students who do not share information through the series of prompts (i.e., group, individual, and then teacher). After collecting information, observations, and measurements, students must then individually deduce patterns from the data. The task-support model then automatically shares the aggregate of student responses to the group using the Deduce! app (Figure 1). Representing similar or dissimilar responses to the group is likely to trigger group discussion and allow students to negotiate and generate a shared understanding about their analysis. Students can change their individual answers after they discuss their answers. To prevent students from simply agreeing on an answer, the task-support model will trigger a constructed response task that asks students to explain how the group has come to consensus about the answer.

Figure 1. Students discuss their analysis using the Deduce! application



In the Deduce phase, the task-support model focuses on providing hints that support students in their negotiation (i.e., another CPS proficiency). These hints can provide expert guidance such as suggesting which trends of the data that students should focus on. The task-support model can also prompt students to leverage the predetermined statements or material scaffolds embedded in their in-game chat tools (i.e., fixed responses). These fixed responses cue students to how to use and apply collaborative problem skills, meaning that it provides students with the expertise that they need to be successful (Quintana et al., 2004). The task-support model also draws on two strategies to promote collaboration, (1) revoicing and (2) encouraging multiple perspectives. The task-support model encourages students to revoice contributions from peers (i.e., "So what you are saying is…") or elicit alternative perspectives ("Does someone have a different idea?"). It is expected that these scaffolds will improve students' proficiencies, moving them from the primary to secondary anchors. Finally, students are expected to demonstrate their proficiencies in collaborative solving as they generate an explanation to the problem when using the TIDE board tool (Figure 2). The TIDE board is the culmination of students' problem-solving processes. Students must share their ideas on which information best support the given explanation, agree and/or disagree with their peers' ideas, and based on the information on the board, reach consensus on why the problem may be occurring. Across the TIDE inquiry phases, the task-support model does not change dramatically, the task support model provides scaffolds with the assumption that the productive discussions with peers and teachers will shift students toward the upper anchors.

Figure 2. Students evaluate whether notes are consistent (or not) with the explanation



Articulating the evidence model

In the evidence model, statistical model and scoring rubrics allow for inferences about student proficiencies based on the task models. Scoring for collaborative problem-solving proficiencies involve attending to process data, or the sequence of actions that indicates students' negotiation strategies during each TIDE phase. For example, during the TIDE board phase, the sequence of actions typically leads to productive collaboration is contingent on moving the notes to denote support or inconsistency, students' individual agreement or disagreement on each note, and the frequency counts of aggregate actions (including chat) when using the board. We expect that each group might engage differently, and some may be more deliberate than others during their discussions. On the other hand, the transitional-evidence model draws on the KSA-change model, which means that the scoring depends on the number of times that scaffolds were utilized by the students. Given that our work draws on learning progressions, which defines categorical competencies (i.e., primary, secondary), diagnostic classification models can be utilized to estimate students' *fixed* competencies (Xu & Zhang, 2016) whereas a Markov model can be used to estimate *change* (Wang et al., 2018).

Significance

In this design paper, we articulate our design of an adaptive collaborative problem-solving system that first diagnoses students' current competencies and provides scaffolds for what learners should do. Because we are primarily interested in scaffolding student learning and moving them towards the desired collaborative problem solving and systems thinking competencies, we articulate the diagnostic assessments and change model in our learning environment. This work provides an innovative design for authentic collaborative problem-solving by utilizing the ZPD to inform our design. Future work will further explore and validate this framework for scaffolding and learning.

Acknowledgments

This research was supported by an Indiana University School of Education Kempf grant and the National Science Foundation through grants DRL-1561655 and DRL-1561486. Any opinions, findings, conclusions, or recommendations expressed in this report are those of the authors, and do not necessarily represent the official views, opinions, or policy of the National Science Foundation.

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