Work-in-Progress—Game Design Informed by Learning Progressions for Science Practices

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***Abstract*—Learning progressions allow researchers to describe key milestones along a pathway of thinking about a topic or practice that ranges from beginner to advanced. For learning related to science practices, some progressions can be abstracted from specific content; others are connected to specific science understandings. This research centers on the design of a middle school science game to support learning of science practices through simulated immersive experiences in which students engage in science practices of experimentation, modeling, and argumentation. This work-in-progress paper describes the application of current research on learning progressions to the design of the game interface and interactions for Aqualab, a game to teach middle school science practices related to aquatic ecosystems.**

***Index Terms*—K12 education, science education, learning progressions, immersive design, game design**

I. Introduction

Learning progressions allow researchers to describe key milestones along a pathway of thinking about a topic or practice that ranges from beginner to advanced. Once understood, these progressions constitute "a framework for connecting standards with curriculum design" [1]. Learning progressions for specific science content have been studied in more detail (e.g., [2]–[5]), but recent research has begun to explore what we can understand about learning progressions for science *practices*.

Digital games can address a current need for teaching science practices in school, through immersive experiences in which participants can engage in active learning with simulated science environments and tools. The Aqualab research project considers how the design of such games can be informed by learning progressions for science practices. Aqualab is an immersive web-based computer game to teach middle school students computational modeling and scientific reasoning in the context of life sciences disciplinary core ideas. In Aqualab, learners will take on the role of an ocean scientist who uses science practices of experimentation, modeling, and argumentation to investigate questions related to aquatic ecosystems. We aim to develop and scaffold layers of science practices within the gameplay, and then to explore how learning progressions can be empirically derived from game data and be operationalized to inform the design of the game itself.

For this work-in-progress paper, we describe our process in applying current research on learning progressions to the design and development of the Aqualab interface and interactions. This spring, we will be testing a pilot version of the game to see how students engage and progress in the game challenges around science practices.

II. Theoretical Framework

A. Learning Progressions for Science Practices

As outlined by NGSS, performance of science tasks requires both understanding of core content and the ability to use science practices to investigate the world and solve problems [6]. There is significant overlap in student learning of content and practices, and assessment of learning progressions may look at blended assessment of content and the practices with which students engage with that content [7], [8].

Research in learning progressions for science practices sometimes aims to differentiate student performances of practice from student learning of content knowledge (e.g., [9]–[11]). For example, Schwarz and colleagues [9] developed a learning progression for modeling in middle school students that focuses on the practice of scientific modeling abstracted from science content. Bamberger and Davis [12] were able to apply this progression to study students' ability to transfer modeling performances across content areas, focusing on general modeling practices such as the extent to which the model explains a science phenomenon. However, deeper learning can also require more sophisticated practice. For example, modeling practices in younger grades may use drawings and physical replicas [9], but shift to more complex practices using mathematical representations or computer simulations to understand more complex phenomena [13].

Another dimension in which students can demonstrate progression in science practices independently of science content relates to *scaffolding* - supports provided so that learners can engage in activities that would otherwise be beyond their abilities [14]–[16]. At first, the task might be structured or

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simplified so that it is easier for the learner to complete. Later as the learner progresses in their expertise, the scaffolding is faded so that the learner is more responsible for the cognitive choices involved in doing the task.

B. Immersion, Learning Progressions, and Game Design

Educational research on the design of learning progressions in game design resonates well with ways that game designers think about progression in gameplay. Games can provide psychological immersive experiences in which players feel caught up in a virtual environment, through engaging situated learning, even on desktop or laptop screens [17]. These games can implement learning progressions through adaptation to players' development of expertise over time, with transitions from easier to more challenging levels, e.g., games in which enemies get more formidable as the player gets more powerful weapons [18]. In order to achieve the sustained focus and enjoyment referred to as "flow" [19], successful games seek to provide continuously challenging experiences within the narrow margin between boredom and frustration [20].

III. DESIGN

Aqualab focuses on the development of three core science practices for middle school students: *experimentation*, *argumentation*, and *modeling*, chosen based on NGSS essential Science and Engineering Practices both because of their relevance and the current challenges they present in classroom instruction.

For each of these practices, we are designing the game with opportunities for students to engage in learning progressions in two ways: (1) scaffolding of tasks that fades as students advance in levels of play and have more control over their engagement in science practices, and (2) opportunities to engage with more advanced tools at deeper levels of complexity as they progress in game challenges. For this paper, we illustrate these ideas using design mock-ups and images from the pilot version of the game.

Aqualab situates the learner as a researcher on an ocean-research ship, selecting and completing "jobs" that require the student to investigate aquatic ecosystems using a submarine to observe and collect data and samples at different underwater sites (Fig. 1), and shipboard tools to conduct *experiments*, construct *models*, and develop scientific *arguments*.

Fig. 1. Immersive ocean exploration for observation and data collection.

Using experimentation as an example, we demonstrate below how existing learning progressions were leveraged to build dimensions of task complexity for the design of the game.

Table I provides examples of some of the ways in which learning goals for experimentation are mapped onto game design. In experimentation tasks, players need to construct an experiment that will provide the information needed to solve the problem presented in the current job. As the student progresses, more variability and options will be unlocked.

Initial Aqualab experiments involve only one choice - simple "observation" tanks where players collect specific behavioral data about organisms (Fig. 2). In later jobs, players will be able to access a variety of tanks, in which they can set up experiments with environmental variables that have increasingly complex implications for ecological systems, such as light, pH, or dissolved oxygen (Fig. 3), and have access to new tools such as microscopes and water chemistry probes. These experiment options will help players solve more complex challenges around phenomena such as photosynthesis. Scaffolding will both restrict initial access to options and provide support from a non-player character (NPC) in suggesting tank setup and identifying experimental outcomes. As students progress in expertise the scaffolding of science practices will fade.

TABLE I. EXAMPLE LEARNING GOALS MAPPED TO GAME DESIGN FOR THE PRACTICE OF EXPERIMENTATION

Learning Goals	Learning progression implemented in game design
Understanding of how to set up a good experiment that involves varying only one thing, independent of content.	Game sets up the experiment correctly for the learner / NPC guides the learner in setting up the experiment.
	Learner sets up experiment on their own.
Understanding of experimental practices related to investigation of more complex science content.	Game provides only one option for experimentation, suitable for simple content.
	Game provides advanced options for experimentation, necessary for phenomena involving more multiple variables or more complex relationships.

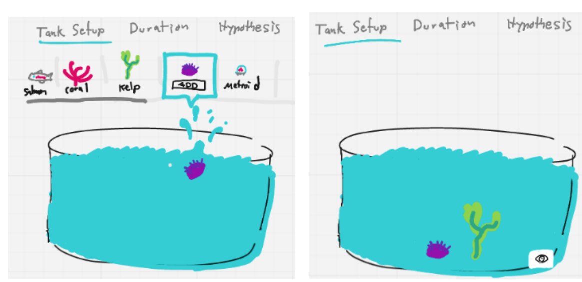

Fig. 2. Initial experiments with simple observation tanks.

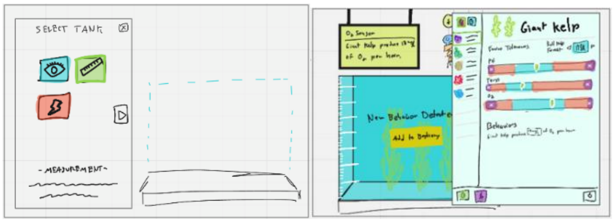

Fig. 3. Choices of tank set up to support experiments related to more complex phenomena.

During play of the game over time, players will be exposed to experiments that are increasingly complex in both dimensions – increased complexity and decreased scaffolding – and the expectation is that student understanding of the practice of experimentation will also progress through game play.

IV. Next Steps

This spring the project team is conducting pilot testing of the Aqualab prototype with 5-6 middle school science teachers and their students. The pilot study will allow students and teachers to play an early version of the game, and will collect teacher and student feedback along with information on student understanding about the tasks. Using a think-aloud protocol, a representative sample of students will play the game over zoom with a researcher who will ask to articulate their thoughts and understanding of the practice-based game mechanics - what do students understand about these practices, and how are they progressing in their use of science practices through game play? We are also piloting a pre-post survey with external measures of student understanding of science practices related to the game, as well as affective measures and general useability questions.

For our presentation at iLRN, we will share the pilot version of Aqualab and our findings about student experiences within the game, as well as teacher experiences supporting students through the game. We will be using the rich data generated by these findings to support development of the full version of the game, and over the following two years, to explore how embedded assessments within the game will be able to evaluate student learning progressions in modeling and scientific reasoning, and be used by the game to identify learner types and provide personalized interventions that improve learning outcomes.

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