Guided Inquiry Learning with Technology: Investigations to Support Social Constructivism

Clif Kussmaul[1][a] and Tammy Pirmann[2][b]
[1]Green Mango Associates, LLC, 730 Prospect Ave, Bethlehem, PA, U.S.A.
[2]College of Computing & Informatics, Drexel University, Philadelphia, PA, U.S.A.

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Abstract: Education needs to be more scalable and more effective. Process Oriented Guided Inquiry Learning (POGIL) is an evidence-based social constructivist approach in which teams of learners work on activities that are specifically designed to guide them to understand key concepts and practice important skills. This paper describes a series of investigations of how technology might make POGIL more effective and more scalable. The investigations include a survey and structured discussions among leaders in the POGIL community, a UI mockup and a working prototype, and experiences piloting the prototype in a large introductory course. These investigations show that instructors are interested in using such tools to provide richer learning experiences for students and better reporting to help instructors monitor progress and facilitate learning. The course pilot demonstrates that a prototype could support a large class and identifies areas for future work.

1 INTRODUCTION

Worldwide, the demand for education continues to increase, while learner backgrounds and aptitudes grow more diverse. Thus, we need to make education more *scalable* and more *effective*. The ICAP Model (Chi, Wylie, 2014) describes how learning outcomes improve as student behaviors progress from *passive* (P) to *active* (A) to *constructive* (C) to *interactive* (I). Thus, students should *interact* with each other and *construct* their own understanding of key concepts using *social constructivist* approaches such as *Peer Instruction*, *Peer-Led Team Learning*, and *Process Oriented Guided Inquiry Learning (POGIL)*. This paper explores ways that technology could make social constructivism more effective and scalable.

The rest of this paper is organized as follows. Section 2 briefly summarizes relevant background. Section 3 describes a set of related investigations: UI mockups and a working prototype; a survey and structured discussions with POGIL community leaders; and experiences with the prototype in an introductory computing course. Section 4 provides conclusions and considers some future directions.

[a] https://orcid.org/0000-0003-1660-7117
[b] https://orcid.org/0000-0003-1797-5843

2 BACKGROUND

2.1 Computer Assisted Instruction

For over 50 years, developments in computing have been applied to education (e.g., Rath, 1967). Typically, a system for *Computer Assisted Instruction (CAI)* or an *Intelligent Tutoring System (ITS)* presents a question, evaluates responses, provides feedback, and chooses subsequent questions (e.g., Sleeman, Brown, 1982; Graesser, Conley, Olney, 2012). However, Baker (2016) notes that widely used ITS are often quite simple, and advocates for systems “that are designed intelligently and that leverage human intelligence” (p. 608). *Computer Supported Collaborative Learning (CSCL)* seeks to use technology to help students learn collaboratively (e.g., Goodyear, Jones, Thompson, et al, 2014; Stahl, Koschmann, Suthers, Sawyer, 2021). Jeong and Hmelo-Silver (2016) describe desirable affordances for CSCL that align with social constructivism: joint tasks; ways to communicate; shared resources; productive processes; co-construction; monitoring and regulation; and effective groups.

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2.2 POGIL

Process Oriented Guided Inquiry Learning (POGIL) is an evidence-based approach to teaching and learning that involves a set of synergistic practices (Moog, Spencer, 2008; Simonson, 2019). In POGIL, students work in teams of three to five to interact and construct their own understanding of key concepts. At the same time, students practice *process skills* (also called *professional* or *soft skills*) such as teamwork, communication, problem solving, and critical thinking. Each team member has an assigned role to focus attention on specific skills; e.g., the *manager* tracks time and monitors team behavior, the *recorder* takes notes, and the *presenter* interacts with other teams and the instructor. The roles rotate so that all students take each role and practice all skills. The instructor is not a lecturer, but an active facilitator who observes teams, provides high-level direction and timing, responds to student questions, guides teams that struggle with content or with process skills, and leads occasional short discussions.

A POGIL activity consists of a set of models (e.g., tables, graphs, pictures, diagrams, code) each followed by a sequence of questions. Each team works through the activity, ensuring that every member understands every answer; when students explain answers to each other, all of them understand better. POGIL activities use *explore-invent-apply (EIA) learning cycles* in which different questions prompt students to *explore* the model, *invent* their own understanding of a concept, and then *apply* this learning in other contexts.

For example, in an introductory computer science (CS) activity, the first model describes a simple game, and questions guide teams to identify and analyze strategies to play the game, leading teams to discover a tradeoff between algorithm complexity and speed (Kussmaul, 2016). Websites have sample activities for a variety of disciplines (http://pogil.org), and numerous CS activities (http://cspogil.org).

POGIL was developed for college level general chemistry, and has expanded across a wide range of disciplines (e.g., Farrell, Moog, Spencer, 1999; Douglas, Chiu, 2013; Lenz, 2015; Hu, Kussmaul, Knaeble, Mayfield, Yadav, 2016). POGIL is used in small (<30) to large (>200) classes. In a literature review, 79% (34 of 43) studies found positive effects and one found negative effects (Lo, Mendez, 2019).

The POGIL Project is a non-profit organization that works to improve teaching and learning by fostering an inclusive community of educators. The Project reviews, endorses, and publishes learning activities, and runs workshops and other events. The Project has been identified as a model "community of transformation" for STEM education (Kezar, Gehrke, Bernstein-Sierra, 2018).

2.3 POGIL with Technology

Prior to COVID, POGIL was primarily used in face-to-face settings, and students wrote or sketched answers on paper. Activities were distributed as PDFs or printed workbooks. Some instructors are exploring how technology could enhance POGIL in traditional, hybrid, and online settings. Tools (e.g., clickers, phone apps, learning management systems) can collect and summarize student responses, particularly in larger classes. Collaborative documents (e.g., Google Docs) make it easier to copy code or data to and from other software tools.

The pandemic has forced instructors and students to adapt to hybrid and online learning (e.g., Flener-Lovitt, Bailey, Han, 2020; Reynders, Ruder, 2020; Hu, Kussmaul, 2021), often using video conferencing tools (e.g., Zoom, Google Hangouts, Skype) and collaborative documents. This highlights the importance of social presence, personal connections, and interactive learning for students, and has thus raised awareness and interest in social constructivism and supporting tools. Software tools also have the potential to leverage interactive models (e.g., simulations, data-driven documents, live code, collaborative documents). Networked tools have the potential to provide near real time data and feedback to students and instructors, which is common in CAI, but less common in social constructivism.

3 INVESTIGATIONS

This section describes a set of investigations, including a user interface mockup, a survey and a structured discussion among POGIL practitioners, a web-based prototype, and experiences using it.

The mockup and prototype are similar to many CAI systems and ITS. They seek to follow the advice (summarized above) from Baker (2016) and Jeong and Hmelo-Silver (2016). However, POGIL provides key differences, including structured student teams, the learning cycle structure, and active instructor facilitation. Teams typically respond to a question every minute or so, so the speed and correctness of their responses should provide valuable insights into how they work and learn, and how POGIL could better support student learning.

3.1 User Interface Mockup

In 2018, a user interface (UI) mockup (in HTML and JavaScript) was developed to stimulate discussion and reflection, and gather informal feedback from the POGIL community.

Figure 1 shows a sample view. (The model is a placeholder and the question text is lorem ipsum to focus on visual form rather than content.) The header (blue) has the activity title, a timer, and a list of sections, for easy navigation. The timer shows the time left in the activity, to help teams manage time effectively. Below the header is a status bar (yellow and green) showing the team's progress (10% of the activity), and how often they responded correctly. Below the header is the section title, which could also include a countdown timer. The section starts with a model; the figure shows a *Data-Driven Document (D³)* (Bostock, Ogievetsky, Heer, 2011), but models could also use text, static figures, or other interactive tools. Below the model is a sequence of questions. The questions can take several forms: multiple choice, checkboxes, numeric value, short or long text, etc. When the team responds correctly, they see the next question. They can also receive feedback, perhaps with a hint for a better response (green).

As described above, a POGIL instructor is an active facilitator, who continually monitors progress, assists teams that have problems with content or process, and leads short discussions. Thus, the instructor's view adds histograms (grey) and/or bar graphs (red, yellow, and green) for each question to show the distribution of responses and timing. The instructor could drill down to see which teams are struggling and might need help, or to find and revise questions that might be difficult or confusing.

3.2 Faculty Survey

In June 2019, a survey was sent to community leaders at the *POGIL National Meeting*. The response rate was 70% (47 of 65). Respondents included college (n=36) and K-12 (n=9) instructors. Disciplines included chemistry (n=38), biology (n=8), and others (n=7). Typical class sizes were <25 (n=23), 25-50 (n=10), and >50 (n=6). These values seem typical of the POGIL community, except that the latter involves a larger fraction of K-12 instructors.

Respondents rated the availability of three categories of technology. Figure 2 (top) summarizes responses, from least to most common. Half (n=25) were at institutions that never or rarely provide computers, and only 14 often or always provide computers. In contrast, about half (n=24) had students who often or always bring their own devices, and only 15 had students who never or rarely bring devices. Nearly all had reliable internet access. Thus, tools should be web-based and device independent.

Respondents also rated their interest in seven potential features. Figure 2 (bottom) summarizes

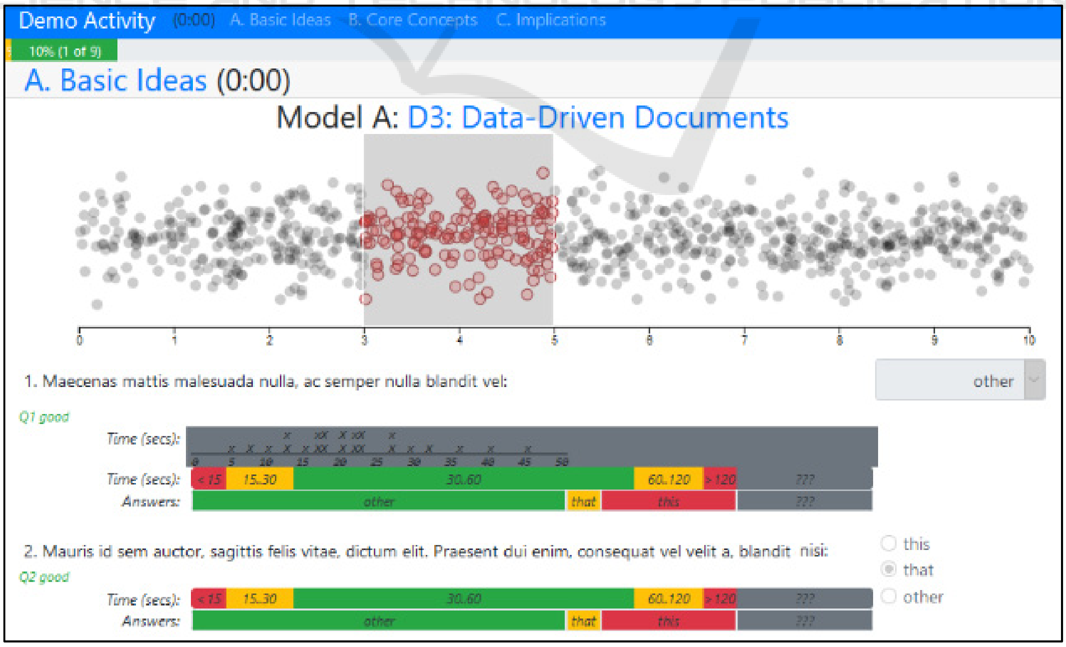

Figure 1: Mockup with pacing cues, an interactive model, and questions with automatic feedback. The instructor's view adds the distribution of time and responses for each question.

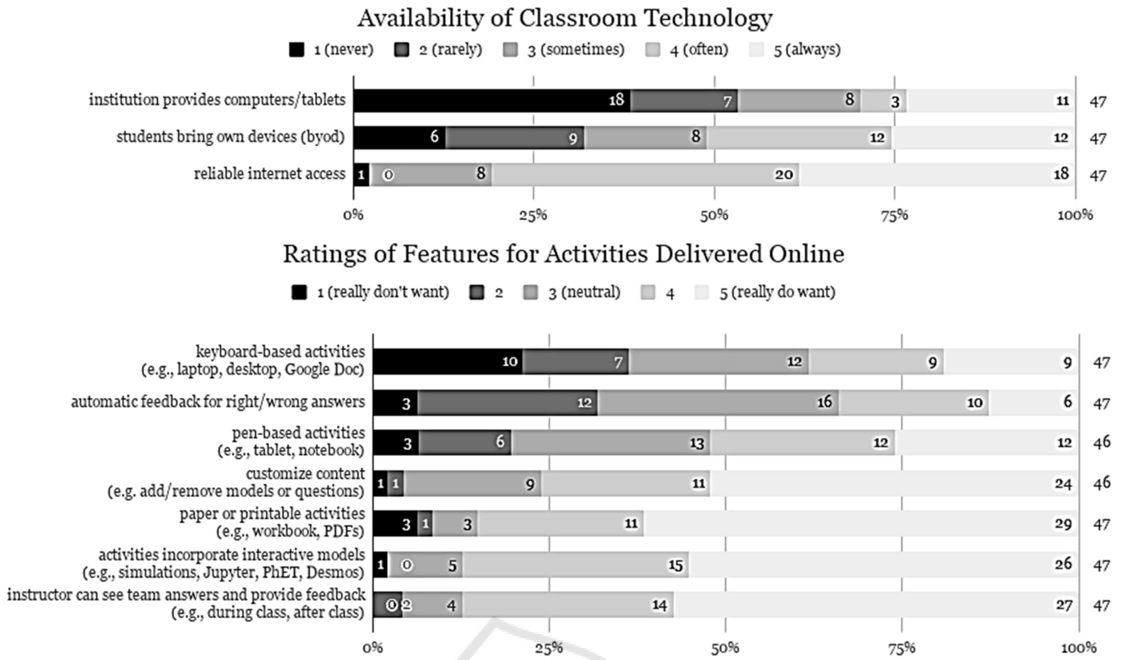

Figure 2: Summary of responses for available classroom technology (top) and features for online activities (bottom). Items are listed on the left, from least to most common. The stacked bars show the number of instructors with each response, from 1 (most negative) on the left to 5 (most positive) on the right. Total responses are shown on the right.

responses, from least to most popular. Respondents were split on keyboard-based activities; 17 didn't want them, and 18 did. This might reflect POGIL's traditional use of paper activities where students draw or label diagrams and other content. Respondents were also split on automated feedback; 15 didn't want it, and 16 did. This might reflect unfamiliarity with such tools, or a strong belief in the instructor as an active facilitator. Pen-based activities were more popular; 9 didn't want them, and 24 did.

Respondents were strongly in favor of the other four features. Most (n=35) wanted the ability to customize content, although this could result in activities that don't meet all POGIL criteria. Most (n=40) wanted the option of paper or printable activities; again, this is common in POGIL. Nearly all (n=41) wanted interactive models and ways to monitor responses and provide feedback. Thus, these became high priorities for the prototype (see below).

3.3 Community Discussion

In June 2020, a POGIL National Meeting session invited participants to "explore the opportunities and constraints that technology can provide", "explore a prototype … for POGIL-style activities", and "have structured discussions about the opportunities and challenges". Twelve participants were selected to provide diverse perspectives, and worked in three groups. In each of three segments, they considered potential benefits and risks for three audiences: (a) students, (b) instructors and authors, and (c) The POGIL Project. Groups then discussed what they had written and identified themes and insights, which were then shared with the larger group. Segments (a) and (b) were preceded by demos of the web-based prototype (described below).

All feedback was copied into a *Freeplane* mind map (http://freeplane.org). Statements with multiple items were split, and similar items were clustered. Table 1 summarizes the most common benefits and risks for each audience; the numbers in parentheses indicate the number of references to each idea.

For students, the top benefits included flexible learning activities in a variety of settings, and a wider variety of models and representations. The top risks included less interaction, more cognitive load, less emphasis on process skills, and technology, accessibility, and usability problems.

For instructors and activity authors, the top benefit was access to data, and specifically real time monitoring of student progress, and data to improve activities, compare classes, and support research. Other benefits included a single integrated platform and sharing activities with other instructors. The top risks included less interaction with students, and added effort to learn new tools and practices and to develop activities and facilitate them in classes.

Table 1: Summary of ideas from structured discussions among POGIL community leaders, to identify potential benefits and risks of a web-based environment for POGIL style activities. Numbers in parentheses indicate number of comments.

	Potential Benefits	Potential Risks
Students	(12) Flexibility for face-to-face, synchronous, asynchronous, and hybrid settings (during pandemic). (9) Variety of models and representations, including simulations (e.g., PhET), easier use of color. (12) Other: student personalization, ease of use, multiple response types, accessibility, lower cost, flexibility, and reduced impact of "loud people".	(14) Less student-student interaction, less discussion and collaboration. (6) More cognitive load and less student focus. (6) Technology issues (rural access, devices), accessibility. (4) Less emphasis on process skills. (9) Other: usability, cost, multiple formats, learning curve.
Instructors & Authors	(24) Data generally (including 6 less specific responses). (9) Monitor student progress and answers in real time, and provide feedback, particularly in large classes. (9) Access to student responses to compare classes, improve activities, study outcomes more broadly. (12) Integrated platform with activity, responses, feedback, reporting out, etc. (vs. using multiple tools). (9) Less work overall, compared to instructors creating and adapting their own online materials and tools. (12): Other: avoid classroom limitations, predefined feedback, use activities from different sources.	(12) Less student-instructor interaction, due to watching dashboard instead of students. (10) Learning curve for tools and facilitation practices. (7) Increased effort to author or adapt materials using new tools (especially answer-specific feedback). (15) Other: cost and reliability, student privacy, focus on answers not process, too little or too much flexibility.
The Project	(13) Data to improve activities and support research. (12) Broader access to POGIL materials, including more adopters, faster dissemination. (8) Increased revenue (without publishers in middle). (7) Push to digital given COVID and other trends. (4) Other: accessibility / ADA, community support.	(24) Time and cost to create system, convert materials, update and support. (10) Security and privacy for student data (and activities). (8) Equity and accessibility. (9) Other: goes against POGIL philosophy, diverse needs, misuse, copyright, subscriptions, third party platform.

Benefits and risks for The POGIL Project were similar to those for instructors and authors. Added benefits included broader access to POGIL-style materials, and possible income to support the Project.

3.4 Web-based Prototype

Based on the mockup and instructor feedback, a web-based platform is being developed to support POGIL and similar forms of social constructivism, and to help instructors create, facilitate, assess, and refine learning activities. *Guided Inquiry Learning with Technology (GILT)* builds on work with social constructivism, POGIL, CAI, ITS, CSCL, and web-based collaboration tools. As described below, GILT focuses on key elements used in POGIL and related approaches, includes features for collaboration and research, and leverages existing tools when possible to avoid overdesign or duplication of effort. (GILT is a single page application using the *Mongo, Express, Angular, Node (MEAN)* software stack.)

With GILT, teams work in a browser, which saves their responses and questions for later review and analysis. In hybrid or online settings, students interact virtually (e.g., in Zoom or Hangouts). An instructor can manage teams and activities, monitor team progress, and review and comment on team responses. An activity author can create and edit activities, and review student responses and timings.

In POGIL, each activity is deliberately designed with a sequence of questions about a model. In GILT, models can be also dynamic and interactive, including videos, simulations such as *NetLogo* (Wilensky, Stroup, 1999) or *PhET* (Perkins, Adams, Dubson, et al, 2005), coding environments such as *repl.it* (https://repl.it) or *Scratch* (Resnick, Maloney, Monroy-Hernández, 2009), and other components, such as *Data-Driven Documents (D^3)* (Bostock, Ogievetsky, Heer, 2011). Questions can take varied forms including plain text, multiple choice, numeric sliders, etc. GILT could also include questions to help assess process skills, mood, and effectiveness.

In POGIL, teams discuss each question and agree on a response; if it is incorrect, the instructor might ask a leading question or - if several teams have the same difficulty - lead a short class discussion. The instructor's notes for an activity might include sample answers and discussion prompts. GILT can provide predefined feedback for common team responses to partially automate this process (particularly when teams are remote or asynchronous), and an author can review a report on the most common responses.

Defining feedback can be time consuming but one author's work could benefit many instructors.

In GILT, an instructor can quickly see the status of each team and the class as a whole, lead classroom discussions on difficult questions, and check in with teams having difficulty. Similarly, an activity author can explore the most difficult questions, the most common wrong responses, and useful correlations (e.g., by institution, gender/ethnicity).

Figure 3 shows a sample view of a model and the first few questions in an activity. The model has some text with background information and two compartmental models. The questions include text, sliders for numeric responses, and checkboxes for multiple choice. For an instructor or author, each question also includes possible responses and advice defined by the activity author, and a history of all student responses. Question 1a has one correct response, and two incorrect responses with advice to students. One team gave two incorrect responses. An instructor could also add team-specific feedback, particularly in settings where the instructor can't easily speak to individual teams.

Thus, GILT seeks to help balance key tensions in the learning experience. Guiding students to discover concepts leads to better understanding but can take longer. Student teams enhance learning but can allow some students to be passive and let others do the work. Automated feedback can help students who are stuck, but can also encourage random guessing. An instructor can provide valuable guidance and support, but might not always be available.

GILT tracks every student response, when it occurred, and when each team starts and stops work on each part of an activity. This can provide near real time feedback to teams and instructors, summary reports for instructors and activity authors, and rich evidence for researchers. For example, authors could examine the distribution of responses and timings to see the impact of adding, editing, or removing elements of an activity. An author could use AB testing to test different forms of a question, different sequences of questions, or different models, and decide which best support student learning. Similarly, researchers could track team and instructor behavior using minute-by-minute data on which views, elements, or subcomponents are used, similar to established classroom observation protocols (e.g., Sawada, 2002; Smith, Jones, Gilbert, et al, 2013).

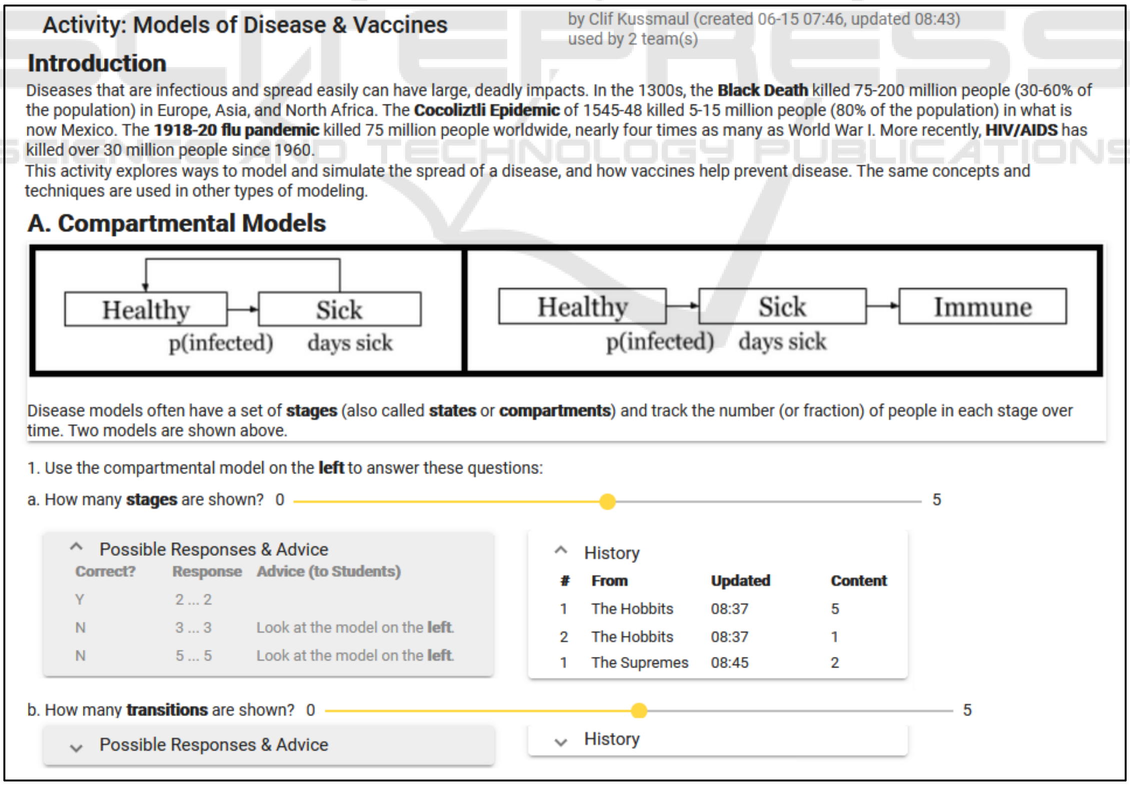

Figure 3: View of a GILT activity, including a model with text and graphics, and questions with numeric sliders. The instructor's view adds possible correct and incorrect responses (shaded); and history of student responses.

3.5 Course Pilot & Student Feedback

In Fall 2020, GILT was piloted in weekly sessions of an introductory computing course with five sections of ~80 students (i.e., ~20 teams per section). The instructor and the GILT developer worked together to migrate learning activities, identify and resolve problems, and clarify future priorities. Migrating activities was usually straightforward, and could probably be supported by undergraduate assistants. Most teams used videoconferencing (e.g., Zoom) to see a shared screen and each other. The user interface was revised to improve clarity for students, and to add information for instructors. It was helpful for the instructor to be able to quickly see the range of student responses, especially for questions that prompted students to develop insights or conclusions.

The instructor reviewed and analyzed end-of-term student course evaluations. Feedback on GILT focused on the POGIL-style class and activities, more than the software platform, and was similar to that in traditional POGIL classes – some students articulate how social constructivism helps them understand concepts and develop skills, and a few dislike teams or believe they would learn more through lectures. Some students wanted smaller teams, and the use of roles was polarizing – some students found them very helpful, others disliked them. As in traditional POGIL classes, it might help for the instructor to more frequently articulate and demonstrate the advantages of POGIL over lecture.

Feedback on the learning activities included ambiguous wording and some repetitive questions. Feedback on the GILT platform focused on some problems saving responses, linking to external sites, and navigating within GILT. Some issues were addressed during the term, and others are in progress.

Here are four student quotes (three positive, one negative; lightly edited for spelling and grammar):

"… one aspect that should absolutely be retained … is the GILT worksheet activities. I feel like they were robust and … where I learned the most … so I ended up learning all that information in a fairly reasonable amount of time."

"These activities were easy to do and introduced us to various new topics while also giving us experience working in a team. I liked how our roles during these activities rotated each week and allowed us to contribute to our group in a different way each time. … the GILT activities were effective because they allowed us to learn new concepts while discussing questions among team members."

"… completing questions [in] GILT is amazing. Not only because it would put us through a new realm of knowledge, but because it forced us to involve in a healthy and fruitful discussion with our peers and helps us to create a new bonding. In fact, I also made a few close friends from this course."

"I feel as though the lecture sessions should be more lecture based and not worksheet filling based. … I might have learned more if I was being told the information, and had to get the answers down on a sheet to show I was paying attention. Because doing the GILT's helped me learn the concepts, but I feel as though if there was a secondary way of learning the information that would have helped me learn better."

4 CONCLUSIONS

This paper has described a set of investigations on how technology could support social constructivism, including UI mockups, a survey and structured discussion among leading POGIL practitioners, a working prototype, and a pilot in a large course.

These investigations have yielded useful insights. Leading POGIL instructors are interested in tools that can support POGIL practices, particularly for classes that are large or physically distributed (e.g., due to a pandemic). Compared to traditional paper activities, software tools could support diverse contexts and interactive models, provide near real time data and reports to help instructors facilitate learning, and enhance communication between teams. These benefits are tempered by concerns about reduced interactions among students and with teachers, and the time required to learn new tools, migrate learning activities, and adapt teaching and learning practices.

Piloting GILT in a large introductory course demonstrated that the prototype could support teams and provide useful data for instructors and activity authors. The pilot also identified some areas for improvement and potential enhancements.

In the future, we will continue to implement, test, and refine technology-based tools to support POGIL. Current priorities include:

- Enhance reporting and dashboards with charts and natural language processing.
- Support responses using tables, matching, sorting, and perhaps sketches.

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