# Agile Research Studios: Orchestrating Communities of Practice to Advance Research Training at Scale

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## ABSTRACT
Undergraduate research experiences enhance learning and professional development, but providing effective training is challenging. Providing effective and scalable research training is often limited by practical implementation and orchestration challenges. This paper introduces *Agile Research Studios* (ARS)—a socio-technical system that greatly expands research training opportunities by supporting research communities of practice without increasing faculty mentoring resources. ARS integrates and advances professional best practices and organizational designs, principles for forming effective learning communities, and social technologies and tools to overcome the orchestration challenge of one faculty researcher mentoring 20 or more students. We present the results of a two-year pilot of the Design, Technology, and Research (DTR) program, which used the ARS model to improve the quality of learning, produce numerous research outcomes, and lower the barrier to participation while significantly increasing the number of students who receive authentic research training.

### Author Keywords
Agile research; community of practice; self-directed learning; regulation skills; socially shared regulation of learning; research training

### ACM Classification Keywords
K.3.1. Computer Uses in Education: Collaborative learning

## INTRODUCTION
Undergraduate research experiences provide numerous personal, professional, and societal benefits including enhancing student learning and broadening student participation and retention in diverse fields of study. Quality mentoring, sustained training, and practicing core modes of thinking in the discipline are crucial factors that contribute to student intellectual growth and interest in science and research careers [41, 45, 18, 42], especially among women and underrepresented minority students [31, 41, 32, 48].

Providing effective mentoring to undergraduate researchers is challenging. Students are required to learn not only disciplinary knowledge, but also the processes, cultures, and mindsets of expert researchers [20]. And those accustomed to quarter- and semester- long class projects may be unprepared for longer term, more open-ended projects that involve greater ambiguity and complexity [25].

Providing effective and scalable mentoring is often limited by practical implementation and orchestration challenges [16]. 1-on-1 mentoring is effective but time-intensive [15]. Faculty researchers must balance the time and effort required for training students with the research group's need for productivity [17]. As a research group expands in size, faculty have less time and attention to mentor each student. Specific challenges include: (a) attending the large number of meetings, (b) days driven by scheduling constraints rather than research importance, and (c) being slow to react to difficulties and contributing to research haphazardly [28]. Scaling effective 1-on-1 research training thus requires overcoming the limitations of faculty member's time.

In practice, faculty reserve 1-on-1 mentoring for graduate students who are more productive. Without significant mentoring, undergraduate students have difficulty engaging in *authentic research* including core activities such as identifying a research topic, formulating a question, determining a research method, designing a plan, collecting and analyzing data, and preparing manuscripts. Graduate students could potentially mentor undergraduates but typically receive little mentorship training and still lack full mastery of research. Without mentoring in core research skills, undergraduate students are usually relegated to rote work such as transcription or tagging, which is less challenging, less engaging, and less likely to produce effective researchers. Some undergraduates perform technical work but struggle without scaffolding and technical support from busy mentors. These practical shortcomings can lead students to discount the value of research experiences and their own self-efficacy [18], resulting in fewer undergraduate students participating in research and few receiving the promised benefits of undergraduate research programs.

The following question drives this research: **How might socio-technical cyberlearning systems train large num-**

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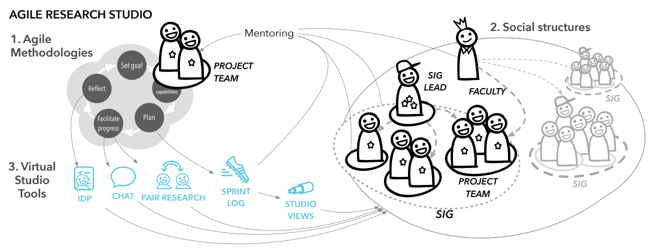


**Figure 1. Agile Research Studios are socio-technical systems that create a research community of practice that socially shares regulation of learning to apprentice undergraduate teams into research at scale. The community of practice help groups learn better together so more undergraduates can conduct independent research.**

**bers of student researchers and produce research outcomes without increasing the orchestration burden on research mentors?** We argue that we can significantly increase the number of authentic research opportunities for undergraduate students by creating research learning communities in which students collaborate to learn and conduct research and develop abilities to be more self-directed [1, 46]. These communities: (a) teach research and collaboration, (b) supportively engage students in independent research work, and (c) train graduate students to become effective mentors and future research leaders. But orchestrating such a community to develop effective researchers faces its own multifaceted challenges. Faculty and graduate student mentors must coordinate research teams with varying levels of expertise, while working on multiple research problems with unpredictable progress. Students must be self-directed learners capable of learning and developing meta-cognitive strategies for achieving desired research outcomes. Learning support must be available beyond usual classroom, research meetings, and office hours.

We propose that a new socio-technical model for research training—*Agile Research Studios* (ARS)—can greatly expand undergraduate and graduate research training by creating sustainable research communities of practice that support students learning to lead research projects, and in which students support one another to learn and make research progress. Agile Research Studios support research training by: (a) adapting *agile methodologies* [44, 12, 30] for the purposes of learning to conduct scientific research through cycles of planning, making progress, and reflection; (b) providing *social structures and processes* for training and support that do not rely on a single teacher; and (c) using *virtual studio tools* to extend the social structures to support learners throughout work cycles using scaffolds, quicker feedback, and quicker connections (see Figure 1).

We argue that the ARS model: allows a faculty researcher to effectively mentor large numbers of students within existing time and resource constraints; develops students' abilities as self-directed learners; and supports learning both in and outside of the classroom [2]. This in turn allows faculty researchers to scale research learning communities that: (a) significantly improve the quality of learning through effective mentorship and support; (b) allow order of magnitude increases in the number of students who receive authentic research training and produce research outcomes; and (c) lower the barrier to participation in authentic research experiences.

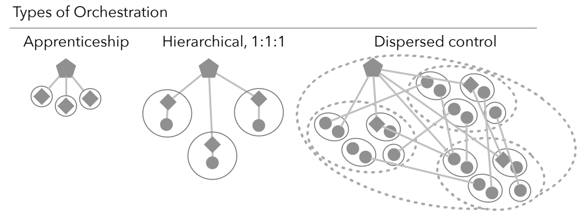


**Figure 2. Only dispersed control and networked orchestration can overcome the 1:X challenge to allow students to conduct authentic research at scale.**

Our early pilot in the Design, Technology, and Research program (DTR) supported a community of 18 undergraduate (44% female), 1 female post-bac, 2 male PhDs, and one pre-tenure faculty researcher. Over six quarters, DTR hosted 36 students who pursued 18 research projects, published 5 papers and extended abstracts at ACM and AAAI conferences, and won 3 awards at major ACM research competitions. While students may enroll in DTR as a single-quarter course, retention beyond their first quarter is at 94%; 64% of students stayed enrolled in DTR through graduation. Students reported significant development in their research and communication skills, and significant increases in their self-efficacy and sense of belonging to a research community.

In summary, our paper makes the following contributions to CSCW:

- *Agile Research Studios* (ARS), a socio-technical system for scaling research training that integrates effective work processes, social structures, and tools to create sustainable research communities of practice that develop students' abilities to be more self-directed, and in which students support one another to learn and make progress.
- A case study of *Design, Technology and Research* (DTR), a research learning community that used the Agile Research Studios model to support a community of over 20 students researchers and one pre-tenure faculty mentor. Results and analysis from a 2-year pilot show how ARS effectively facilitated students' learning to conduct research work and built a supportive community in which students regularly provide and receive help.

## BACKGROUND

It may be possible to scale 1-on-1 research mentoring by situating research activities within a community of practice [47]. Learning communities [4, 8] leverage the diversity of member expertise, value individual contributions, support continual advancement of knowledge and skills, emphasize learning how to learn, and provide mechanisms for sharing what is learned. We aim to apply the insights and design principles of learning communities to support research training for large numbers of student researchers.

Apprenticeship provides a powerful model for training young researchers but imposes an enormous *orchestration* burden [16] on individual faculty researchers who can only mentor a handful of students at a time. Scaling research apprenticeship requires overcoming the "1:X" challenge of allowing one teacher to successfully respond to the learning needs of many students [2] (see Figure 2). In the *1:1 apprenticeship* model, students work directly with senior researchers. This form of research training is effective but labor-extensive, as it "...requires a very small teacher-to-learner ratio that is not realistic in the large educational systems of modern economies [15]." Thus, apprenticeship is typically reserved for graduate students who are more productive and rarely provided to undergraduates. In the *hierarchical, 1:1:1* model, faculty mentors delegate undergraduate mentoring to graduate students. But graduate students themselves have yet to fully master research, let alone effective methods for effectively guiding others [43]. To overcome the shortcomings of 1:1 and 1:1:1 models we must ultimately disperse control of orchestrating learning and support across a network of student researchers [2].

Our research investigates technology, practices, and organizational structures that support a community of undergraduates learning to conduct research. We focus on orchestrating the development of *regulation skills*, i.e., cognitive, motivational, emotional, metacognitive, and strategic behaviors for reaching desired goals and outcomes [29, 33]. Student researchers must develop regulation skills needed for conducting authentic research that demands (a) self-directed research planning, monitoring, reflection, and replanning [1]; and (b) adopting effective help-seeking and collaboration to overcome challenges [35, 33]. We argue that *developing regulation skills will permit student researchers quicker access to more central activities within the community of practice* that provide authentic research experiences that are more likely to lead to the desired learning and work outcomes.

Training and support for developing regulation skills is time-consuming for mentors and difficult to support with software alone [29]. However, we may be able to overcome this orchestration challenge by creating socio-technical systems that: (a) develop students' research ability and self-directed learning skills so that they self-regulate learning (SRL) to conduct research more independently; (b) promote student teams' socially shared regulation of learning (SSRL) so teams orchestrate their own learning; and (c) connect undergraduate and graduate students to mentors, peers, resources, and instruction to co-regulate learning (CoRL) so that students support each other beyond immediate project teams [29, 33, 1]. We argue that orchestrating research communities in which students learn regulation skills at scale will allow faculty researchers to support large numbers of undergraduate researchers in ways that respect faculty mentors' time and their need to make effective research progress.

Our solution, *Agile Research Studios* (ARS), uses agile methodologies [12, 30] to scaffold regulation learning through short cycles of research planning, progress making, and reflection. Many professional agile teams provide in-person support for making progress, helping, and replanning on a daily basis. These practices are effective but difficult to implement with undergraduates performing research part-time, who have packed academic schedules and numerous competing demands. We face the added challenge that: (a) students lack regulation skills and (b) research planning requires significant discipline knowledge and may be more difficult for novices than planning in professional settings. We address these challenges by adapting agile methodologies to fit faculty and student time constraints, providing social structures for teaching agile research planning, and extending support with virtual studio tools that facilitate help-seeking and collaboration.

## AGILE RESEARCH STUDIOS

Agile Research Studios support students in (a) learning self-directed research planning, monitoring, reflection, and replanning; and (b) adopting effective help-seeking and collaboration to advance learning and support progress-making. First we investigate how to support student researchers learning to effectively plan research work:

> **RQ1**: How can we orchestrate learning and support for student researchers in Agile Research Studios to effectively plan authentic research inquiry, monitor and reflect on their progress, and make adjustments?

Undergraduate researchers lack skills for forming feasible and effective research plans, monitoring these plans as work progresses, and adjusting these plans in response to the inevitable challenges that arise in the course of research [1]. Students may reflect on and share their progress infrequently, even though reflection and sharing what one has learned are vital metacognitive skills [40, 9, 14]. When faculty prioritize short term research productivity, they may use 1-on-1 mentoring meetings predominantly for communicating work progress and overcoming technical problems. As a consequence, teaching self-directed planning and reflection is often deferred.

To overcome these challenges, Agile Research Studios help students develop research planning skills through *sprint planning meetings* that connect researchers through *special interest groups* (SIGs) that plan work at frequent intervals following agile methodologies. This meeting facilitates peer review and feedback by mentors and students to help student teams develop their planning skills and devise strategies to overcome challenges [29, 33]. To help student teams learn planning, students record tasks and progress in *sprint logs* that support students' and mentors' awareness of progress and potential needs for replanning. To promote reflection, student teams use *research logs* to record and reflect on research progress throughout a sprint and complete self-assessments in the form of *independent development plans* at quarterly intervals.

Together, our sociotechnical system (a) extends student researchers' ability to perform complex planning tasks and mentors' awareness of team plans; (b) connects teams to SIGs; and (c) develops agile planning and research problem solving. Our evaluation will demonstrate how SIG meetings and tools support students' learning to plan research inquiry, promote sprint planning activities, teach students planning best practices, and help students and mentors to identify problems and readily make adjustments.

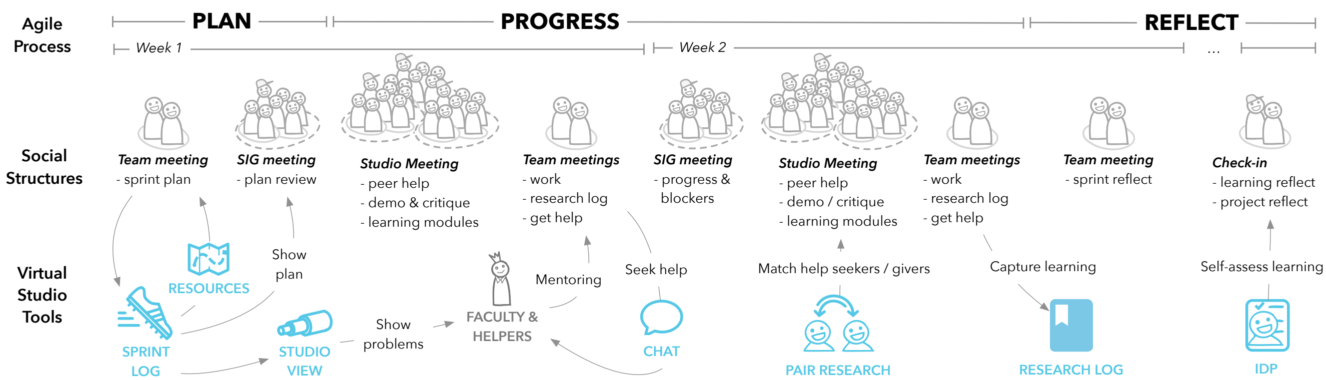


**Figure 3. Agile Research Studios support regulation by adapting agile methodologies to research through 2-week sprint cycles of research planning, progress making, and reflection. Social structures help to orchestrate research activities by (a) supporting learning self-directed research planning, monitoring, reflection, and replanning; and (b) facilitating help-seeking and collaboration to promote learning and progress-making. The virtual studio tools extend social structures to more effectively orchestrate learning and support in and out of the classroom.**

Our second focus area examines how we might orchestrate help-seeking and collaboration to facilitate progress and learning. Specifically, we ask:

> **RQ2**: How can we orchestrate help-seeking and collaboration in an Agile Research Studio to effectively leverage the distributed expertise of its members to support progress-making and learning?

Without sufficient guidance, student researchers can easily become lost, confused, and frustrated [23]. Students may waste a significant amount time before seeking help and may only seek help from their teammate or mentor. Students often need additional help-seeking skills in order to learn effectively [35, 36, 39]. Help-seeking is particularly challenging in research because: (a) research is open-ended, and pinpointing what help is needed, or even knowing whether one can solve a problem quickly, is difficult for students; and (b) the research community consists of many individuals working on different projects, making the task of identifying, selecting, and enlisting qualified helpers more difficult. While senior mentors are the most capable of addressing a wide variety of needs, their availability is most limited and awareness of who most needs help is low.

To overcome orchestration challenges of help and collaboration, Agile Research Studios provide *virtual studio tools* that support students recognizing their needs for help and that connect them to helpers across the studio. For example, *pair research* [34] elicits students' needs for help and connects students to others that can best help them in studio. *Chat* programs such as Slack enable students to seek help on-demand and coordinate in-person or virtual helping sessions. Beyond tools, Agile Research Studios establish a variety of social structures and community practices to promote help-seeking behaviors and support students connecting to helpful peers and mentors in and out of their SIG.

Together, ARS: (a) extend student researchers' help-seeking ability and mentors' availability for help and awareness of team progress and blockers; (b) connect all individuals to make social connections, and help-seekers to help-givers; (c) develop help seeking dispositions as well as domain knowledge and skill. Our evaluation will demonstrate how Agile Research Studios increase the number of help-seeking episodes, the variety of help sought, and the number of people helping across the community of researchers.

### The ARS Model: Processes, Social Structures, and Tools

Agile Research Studios support a research community of undergraduates, graduates, and faculty with varying interests, expertise, and experiences to (learn to) conduct research. A studio is typically organized around a broad research theme that matches a faculty mentor's research interest. Studios can fit within typical academic calendars and allow students to continue for multiple quarters or semesters to promote deep, interest-driven learning and to develop research skills and products over time. *All students, regardless of seniority, conduct independent research and receive authentic research practice.* Students and mentors pursue projects that match their mutual interests. Each project team is kept small (1–3 people) to promote research ownership.

Agile Research Studios consists of (a) *agile methodologies* for scaffolding learning regulation skills, (b) *social structures* that sustainably orchestrate learning regulation skills, and (c) *virtual studio tools* that extend social structures to orchestrate learning regulation skills and support progress-making in and out of the classroom. Figure 3 provides an overview of the components and interactions among the processes, social structures, and tools that collectively describe how we propose to create Agile Research Studios.

#### *Agile Methodologies*

Agile Research Studios support students' development of regulation skills by adapting agile methodologies [44, 12, 30, 28] to research through 2-week *sprints* that cycle through research planning, progress making, and reflection processes. Agile methodologies have been used by software development and design teams to support adaptive planning, early delivery of value, continuous improvement, and rapid and flexible response to change. Agile teams meet regularly for project planning, updating on progress, and overcoming blockers. This process promotes productivity and focus, sharing progress, identifying difficulties early, replanning, and reflecting on progress to improve future plans. *We hypothesize that the agile process is particularly well-suited for student researchers learning regulation skills and conducting scientific research.* Benefits include learning to set appropriate and feasible goals, devise strategies for making progress and overcoming blockers, and growing their project in complexity and generalizability as their skills and the research work matures.

### Social Structures

To support student researchers learning regulation skills within a community of practice and to scale faculty time, we propose three social structures to orchestrate shared regulation of learning throughout each sprint:

1. **Team meetings** bring together students on the same project to: (a) make sprint plans; (b) perform research; (c) get in-team help; (d) record progress through *research logs* [38]; and (e) reflect on sprint outcomes.

2. **Special Interest Group meetings** (SIG meetings) bring together undergraduate students, graduate students, and faculty working on different projects in the same research area [47]. Each SIG is its own mini-studio initially led by a faculty member whose leadership fades over time as a graduate student *SIG lead* gains competencies in mentoring and becomes the leader of their own SIG. At the start of a sprint, teams share the outcome of their last sprint and present their current sprint plans for review. Halfway through a sprint, teams present their progress and SIG members help devise strategies for overcoming blockers.

   The purpose of planning together is to help students gain regulation skills [29]; student receive coaching and feedback from mentors and peers to increase learning [14, 1, 27, 26]. Mentors and peers prompt teams to: (a) describe how their sprint stories and tasks connect to their research goals; (b) clarify what the actual deliverables of the story would be, and what value it would have; (c) consider alternative plans; (d) assess whether stories can feasibly be completed in time; and (e) generate strategies for better *slicing* [13] work. While newer students receive more scaffolding and direction, senior students are challenged to demonstrate and practice their regulation skills in formulating and revising plans.

3. **Studio meetings** bring together all researchers in a studio to promote progress, learning, and collaboration across SIGs. The studio meeting consists of: (a) *work time*, during which students work on their own projects, (b) *peer help*, during which students formally or informally seek and receive help from others; (c) *demo & critique*, which allows students to share work progress and receive valuable feedback from the entire community; and (d) *learning modules*, which are led by faculty members and students to share "tools of the trade" and teach research skills that benefit all students. Studio meetings embed students in a larger community of practice beyond the problem domain of their SIG. Multifaceted community support provided via multiple mechanisms address diverse students needs at different stages of research and their personal development.

These social structures support students meeting in-person to plan work, conduct research, provide and receive help, and reflect and share progress. Depending on its purpose, meetings can be 1-on-1, in small groups, and across the entire studio. To further support student reflection and developing over time, bi-quarterly *check-in* meetings facilitate faculty and graduate student mentors meeting with students individually and in their teams to reflect on their learning and project progress. We hypothesize that these social structures effectively orchestrate learning regulation skills at scale by: (a) reducing the need for the faculty member to have regular 1-on-1 meetings with each student team; (b) supporting the role of students as self-directed learners, and (c) conceptualizing learning spaces and places as opportunities for active collaboration and exchange.

### Virtual Studio Tools

To effectively orchestrate learning and instruction, we have developed *virtual studio tools* that extend social structures and in-person meetings to orchestrate learning and support progress-making in and outside of the classroom [24]. Virtual studio tools support 3 interrelated feedback loops: (a) a sprint planning and replanning loop in which students and mentors receive feedback on project plans and progress, (b) a help and collaboration loop that helps students scope help requests and connects to helpers, and (c) a reflection loop that promotes awareness of learning and project progress to support growing over time. We describe below the affordances that virtual studio tools should provide:

1. **Sprint Logs** are interfaces that allow student teams to record all tasks they plan to do for a sprint, update task progress throughout a sprint, and replan as needed (see Figure 4). Following professional sprint planning practices, students use the sprint logs to enter high-level deliverables, or *stories*, and the *tasks* for completing those stories. To prioritize work, students assign *points* to stories and tasks to estimate the value of the work to the research and the effort required to complete it. This helps students to think through the process of scoping out work that they can feasibly accomplish within a sprint that deliver value for their research. During a SIG meeting, displaying the sprint log facilitates students, peers, and mentors communicating their plan, reporting progress, and devising strategies to overcome blockers.

2. **Resources** are references and guides that describe how to achieve commonly shared stories and tasks, such as writing a paper or setting up a technology. While students work on different projects, within an ARS there is likely to be significant overlap in methodology that allow for similar resources and guides to be useful across projects. We curate these resources and provide affordances for students to find helpful resources from their sprint log and to suggest resources to others during SIG meetings.

3. **Studio Views** are dashboards that summarize the sprint logs of all teams. This helps surface potential problems to mentors by helping them see at a glance progress across teams. For example, a mentor can see which teams are behind on a sprint and connect with those teams for a quick

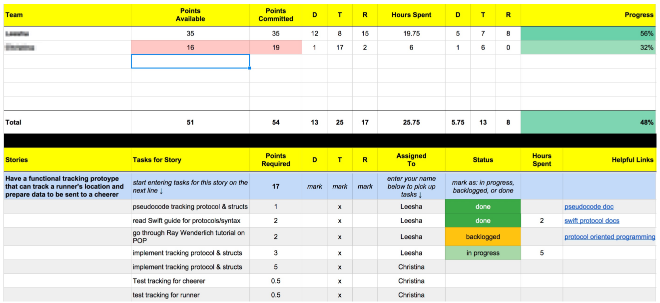


**Figure 4. Screenshot of a spreadsheet prototype of a project team's *sprint log*. The top half of the sprint log provides an overview of commitments, hours spent, and progress on the current sprint. Students plan their sprints in the bottom half of the sprint log. Students plan high-level deliverables, or *stories*, and the *tasks* for accomplishing those stories. Students use a *point system* to estimate required effort to avoid committing more time than they have available for the sprint. As students make progress they mark tasks as *done*, *backlogged*, or *in progress* and record hours spent. Students link to resources that (a) they found themselves; (b) that others in their SIG suggested; and (c) that were auto-suggested from a collection of studio curated resources and the Web via a keyboard shortcut.**

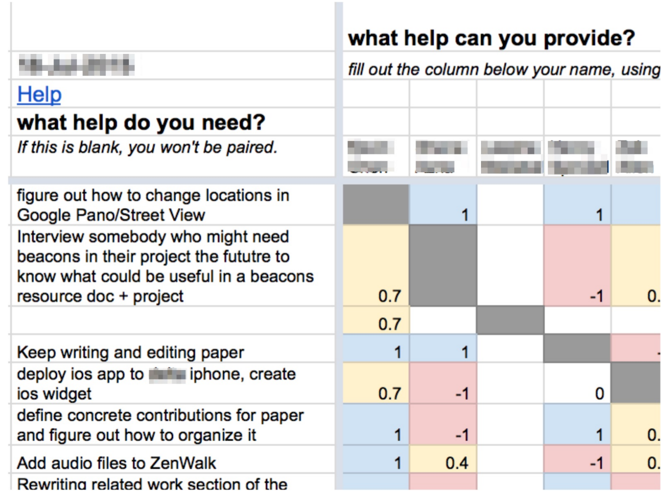


**Figure 5. Screenshot of a Google Spreadsheet prototype of the *Pair Research* tool. Students enter their needs for help and how well they can help others. Based on collected preferences, the system automatically pairs students to help each other on diverse research needs.**

check-in or an impromptu office hours to resolve larger challenges as needed.

4. **Chat** is a collection of online chatrooms, each with a dedicated topic. Chat provides a medium for students to reach out to mentors and peers for help online and on-demand. We replicate the social structures of Agile Research Studios by providing chat rooms for project teams, SIGs, and the whole studio. We also create rooms to support other community needs such as planning fun activities or discussing interview candidates. Team and studio members can connect through private messaging, and use bots to stay aware of others' activities and facilitate progress updates.

5. **Pair Research** [34] is a system for pairing students to help one another on their respective projects based on student reported task needs and their ratings of how well they can help others (see Figure 5). By finding globally optimal matches across a studio, pair research distributes the provision of help across the community of learners within studio meetings to make effective use of the community's collective expertise and time resources. This in turn frees up faculty and graduate student mentors to provide help where they are most needed.

6. **Research Logs** are personal diaries in which students are prompted to capture and reflect on their research progress and learning [40]. The research log serves primarily as a research diary rather than a tool for communicating research plans (as the sprint log is for).

7. **Independent Development Plans (IDP)** are a set of close- and open-ended questions about project progress, including what challenges students encountered, how they overcame challenges, what challenges remain, and perception of personal growth. IDPs help students self-assess their learning and progress. Questions are divided into sections on Research Work, Collaboration, Growth, Research Process, and ARS Process to promote students reflecting on different facets of their work progress and development as self-directed learners.

We have created initial prototypes of all of the virtual studio tools described above by using, building on, and integrating existing and free collaboration and communication tools including collaborative editors (Google Spreadsheets; Google Docs) and team messaging programs (Slack). Figure 4 shows a Sprint Log we prototyped using Google Spreadsheets that supports student teams planning their work, sharing their work progress, and linking to helpful resources in Google Drive and from the Web.[1] A spreadsheet-based Studio View prototype loads student teams' sprint log data and displays to mentors how far along teams were on their sprint versus how much time was left in the sprint. We use Slack as our chat program and created a spreadsheet prototype for Pair Research (see Figure 5). Students maintain research logs using Google Docs and store their project files in personal cubbies in Google Drive folders. The IDP is implemented as a self-assessment Google Spreadsheet.

*Participation Conditions, Project Selection, and Social Norms*

With more demand than available mentoring resources, we use structured interviews following industry established best practices [5] to select students who are prepared to make research contributions within a research learning community. Similar to advanced classes and labs, students joining an ARS are required to have the requisite subject area expertise. Beyond subject area expertise, we select for students who show aptitude for embracing collaboration, growing through challenges and failures, taking initiative, managing ambiguity, and seeking deep understanding [46]. Given limited interviewing resources, students in an ARS interview candidates

[1] While project management tools for agile teams exist (e.g., Jira, Pivotal Tracker, and Trello), they lacked (1) one or more desired affordance for recording, tracking, and sharing stories, tasks, points, and progress; (2) ways to easily integrate Studio Views and Resources; and/or (3) support for collaborative editing.

together with the faculty mentor and recommend other students who they think are good candidates for joining the ARS.

To promote student engagement and ownership of their project, students select the project they work on in the SIGs that they are interested in. The faculty mentor meets with incoming students to brainstorm project ideas and discuss project fit and the technical training necessary. The mentor helps students identify a set of scoped project ideas that are feasible for the student and are likely to lead to research contributions of interest to the SIGs the student is interested in. Students have the final say on which project they choose from this set. Students may change projects when their project comes to a close or their interests change; the faculty mentor also supports students selecting a new project in such cases.

An ARS may establish a variety of social norms to promote a culture of collaboration and to help students build regulation skills. For example, to promote effective help-seeking, students may be frequently reminded by mentors to ask for help if they are stuck for more than 30 minutes. To emphasize the importance of learning regulation skills, students may receive positive feedback from mentors for trying to regulate (e.g., exhibit understanding of their planning processes, or trying to clarify goals and decide among alternative plans) rather than praise for students' successful work outcomes. This is consistent with helping students develop a growth mindset [19] for learning and practicing regulation skills.

## METHOD

We take a design-based research (DBR) approach to develop the ARS model for overcoming the orchestration challenges of research learning at scale. DBR [10, 7, 11, 37, 21] requires iterative cycles of defining design arguments (hypotheses), implementing the design argument, collecting data, evaluating the design, and refining the design. We study the ARS model through a case study of the Design, Technology, Research (DTR) program, a research learning environment of 20+ students implemented and led by one of the authors.

### Context: Design, Technology, and Research (DTR)

The DTR program was implemented at a private US research university in Spring 2014. The goal of DTR is to realize and develop undergraduate and graduate students' potential for developing novel technologies and creative solutions through design, engineering, and research. Such practice is often lacking in lecture-based classrooms yet is crucial for preparing students for the complex social and technical problems they will face in STEM careers [25]. As participants in this for-credit program, students lead research projects in social and crowd computing, cyberlearning, and human computer interaction.

In repeated 10 week-long studio sessions, students work with mentors to identify a research project, explore and iterate over designs, prototype at varying fidelities, build working systems, conduct evaluative studies, and report findings through progress reports, blog posts, workshops, and conference publications. Students follow the entire research process each session; projects grow in complexity and generalizability over multiple studio sessions.

Students learn about DTR through word of mouth, recruitment emails, and course catalogs. They apply to join the DTR program and receive course credit for enrollment. Student can enroll repeatedly to satisfy computer science major course requirements or as an independent project course. Students are not obligated to stay in the program though the majority of undergraduate DTR students continue in DTR until they graduate.

#### *Design Iterations*

Over a span of two years from Spring 2014 to Winter 2016, we iterated on the structure, practices, and tools of the DTR studio to arrive at the design arguments for Agile Research Studios we presented in the previous section. The DTR studio grew over time; our initial studio had 8 undergraduate students; our current studio has 18 undergraduate students, 1 post-bac researcher, and 2 second-year PhD students. While the faculty mentor initially had 30 minute 1-on-1 meetings each week with each student and followed up via frequent office hours in-person and online, this quickly became impossible to orchestrate as the studio grew. This led us to adopt the SIG structures we proposed. In SIG meetings, we did not initially have a formal sprint planning process and instead used research logs to communicate progress and plan next steps. But the time required to get grounding took up valuable meeting time and did not scale as SIGs grew in size. This inspired the use of agile methodologies for planning and tracking sprints. But at first, students planned sprints but did not record their progress; this made it difficult for communicating progress and for identifying where help is most needed. Now, students log progress and hours in their sprint log, which facilitates teams sharing their progress and blockers.

### Data Collection and Analysis

To study the participation, productivity, and learning outcomes from the ARS model we collected records of students' enrollment in DTR, tallied major products produced, and analyzed student quarterly self-assessments. We deductively coded the self-assessment reports for students' perceived development of subject-area expertise (i.e., in design, technology, and research); learning of regulation skills (i.e. in planning and help-seeking); shifts in self-efficacy, attitudes, and dispositions; and sense of belonging in a community.

To study how students planned and replanned their work, we used the Google Drive API to collect the revision histories on each project's sprint log over the two completed quarters during which the tool was deployed (Fall 2015 & Winter 2016). Each revision represents a set of edits grouped into a short time period. We also recorded the final status of each sprint, including points commited, hours sprint, tasks completed or backlogged, and resources linked.

To study students' helping behaviors, we surveyed students for the names of people they helped and were helped by in DTR each quarter, as well as what they helped with. This survey was included as part of the self-assessments in the last four quarters (Winter 2015, Spring 2015, Fall 2015, Winter 2016). We coded each instance of help by the type(s) of help requested and fulfilled, divided into subcategories within design, technology, and research. To understand how helping behaviors may be affected by social structures in DTR, in our analysis we combined the helping data with a graph of the closest relationship between each pair of students as teammates, SIG-mates, or studio-mates each quarter.

To understand how students connected outside of in-person meetings, we collected Slack usage statistics and public message histories during the six-month period from November 7th, 2015 to May 5th, 2016. While Slack's team statistics webpage only surfaces basic stats on the front-end, it contains within its source code a JSON data object with a more detailed breakdown of the number of messages sent in the channels and groups that the authors are a part of. We used this data for our analysis.[2]

## DTR PILOT STUDY RESULTS

Our initial pilot of DTR used the Agile Research Studios model to provide authentic research training to a large number of students. Over the last two years from Spring 2014 to Winter 2016, we have hosted six academic-year, quarter-long studios with 4 graduate students (3M, 1F) and 32 undergraduate students (22M, 10F). In the Winter 2016 studio, we hosted 21 students (2 PhD, 1 post-bac, and 18 undergraduate) who led 13 research projects. 43% of the students in this studio were female (9 out of 21).

DTR students iteratively designed, built, and user tested 18 new systems. 19 students have received university undergraduate research grants. Five student papers and extended abstracts have been accepted at ACM and AAAI conferences, and four student-led full papers are currently under review. Three DTR students placed 1st, 2nd, and 3rd at major ACM student research competitions. Undergraduate students in DTR are applying to top PhD programs and receiving internship and full-time positions at top tech and design companies such as Apple, Google, Facebook, Microsoft, Yelp, IDEO, LinkedIn, FitBit, and Vox Media.

While students were not obligated to stay in DTR beyond a quarter, 94% of students completed at least two quarters of DTR (34 out of 36 students). Students who have graduated stayed in DTR for an average of 3 quarters; 64% of them continued in DTR until they had graduated (14 out of 22 students). 12 out of the 36 students left DTR before graduating. They cited a number of reasons, including being more interested in building technology than the research work (4), needing to finish course requirements to graduate on-time (4), switching to another research area and lab (2), and having completed a PhD rotation (2). Only 3 of the 12 students who left DTR are female, of whom two needed to finish graduation requirements and one had completed her PhD rotation.

With the community structure for planning and support in place, the faculty mentor was able to orchestrate DTR with 2 PhD students, 1 post-bac researcher, and 18 undergraduate students leading 13 research projects with less than 12 hours of faculty time each week. The faculty member used: 5 hours for SIG meetings (five SIGs each with up to 3 active projects and 6 students), 3 hours for the all studio meeting, and 4 hours for in-person and virtual help to respond to students on demand. On typical weeks, the faculty mentor was able to maintain awareness of progress across projects and had time to respond to research challenges that they themselves can best address. On "surge weeks," e.g., when approaching paper and grant deadlines, the faculty mentor spent considerably more time reviewing drafts, editing, and helping out in any ways needed.

Student self-assessments and exit interviews from the pilot showed significant gains in student learning about design, technology, and research, development of regulation skills, and increases in innovation self-efficacy [18]. Students noted that DTR helped them better understand the spectrum of research processes, positively impacted their attitudes toward academic research, and led to significant shifts in their attitudes and beliefs in their ability to develop novel technologies and conduct STEM research. We discuss in detail below the perceived learning outcomes, significant shifts in student disposition, and students' sense of belonging in a supportive community.

### Self-Reported Skill Development in DTR

Students reported learning a wide range of user-centered design skills including needfinding, storyboarding, paper prototyping, and user testing. Students noted that DTR "really reinforced the iterative design approach" and how crucial frequently testing is for making effective progress and better understanding the problems they worked on. Students also reported learning a wide range of technical skills, including iOS development, modern web development, Google Glass development, video streaming, asynchronous programming, working with APIs, server management, and databases. Students reported growing as developers, system architects, and collaborative programmers, and in their abilities to work as software development teams.

Students reported learning a wide range of research skills including framing a problem, understanding related research, designing user studies and experiments, preparing an IRB application, conducting user studies, interviewing and surveying, analyzing results, writing an academic paper, and presenting work to an academic and general audience. Students reported gaining a better understanding of what conducting research entails, developing mindsets of "completely owning [their] project," learning to lead research inquiry, and viewing themselves more as "a contributor rather than just a student." Through preparing papers, presentations, and research grants, students reported developing effective communication skills and noted the importance of learning to communicate their research effectively to a general scientific audience. Students also reported that writing and presenting helped them gain a better understanding of the significance of their work, which contributed to their longer term vision and understanding of their research questions.

### Self-Reported Development of Regulation Skills

*Research planning, monitoring, reflection, and replanning*

[2]This data does not include private channels that students may have created to which the authors were not invited, nor the contents of any private messages among students.

From self-assessments, students reported developing planning skills to drive effective research inquiry by using sprint planning to help them break down big tasks into smaller goals, prioritize goals, and to "see what success looked like at every step." Students reported developing a number of strategies and skills for delivering value within two week sprint cycles, including (a) building at the fidelity appropriate for the current stage of research, (b) prioritizing important features and research questions, (c) sequencing tasks, (d) defining concrete outcomes, and (e) moving on despite uncertainty or imperfect knowledge. Students noted learning the importance of being able to reason about alternatives and to understand tradeoffs. Beyond individual sprints, students also reported learning to perform "careful prior planning with end goals in mind" at the quarter level to ensure that they completed studies and met paper deadlines.

Students reported developing metacognitive strategies for effectively planning and conducting open-ended research. In order to respond effectively to failures and changes in project needs, students recognized the need to be flexible, to reevaluate their goals frequently, and to pivot as needed. One student notes: "Failure is a huge part of research, and even if it's frustrating and disheartening, it doesn't invalidate your previous results or progress. You can pivot. Some hypotheses will not be proved, and you need to continue to design studies and build technologies to test other hypotheses."

Students also reported developing strategic planning skills commonly seen in experts yet rarely adopted by novices [6]. Many students struggled initially with effectively planning their design and technical work around their research contributions. Instead of focusing on stories that yielded clear research value (e.g., that tests a design argument), students planned and spent too much time on stories around complex features that were less critical to the research. With mentoring, these failures led students to develop more effective strategies over time. Students reported learning to conduct iterative, small-scale tests to orient their research direction, prioritizing tech features to answer research questions, syncing their hypotheses and study designs to their technology, and avoiding "getting sidetracked by other nifty design features and remember that everything has to be tied back to research outcomes."

### *Help and Collaboration*

Many students reported being willing to ask for help whenever they needed. Students overwhelmingly reported an increase in their willingness to seek out help as they participated in DTR. "I think I did a much better job with help-seeking this quarter," one student wrote. "There were probably only two times where I got stuck and sat on it for a little bit before asking for help." DTR students reported adopting a number of effective help-seeking strategies rarely practiced by undergraduate students [35, 36, 39], including doing a little bit on their own to help them formulate help requests better, asking for help online and offline, "expanding [their] network of help-givers and receivers with the new class [of incoming students]," and learning to become more comfortable with asking for help by starting now.

Students recognized the importance of recognizing blockers that impeded their progress and seeking help to overcome them. Through less productive sprints, students learned that it "is detrimental to try to work through blockers on your own. Asking for help should be the first step when you really get stuck on a blocker." Students noted their struggles in "admitting that something I'm doing is not working" and being "adamant in fixing things on my own." They commented that DTR "taught me to acknowledge when I need help and that it's perfectly acceptable and important to ask for that help." Students also acknowledged the need to ask for help quickly, to not wait till the next SIG meeting and to instead reach out to mentors "more often as that could have prevented the issues I faced or at least I would have discovered earlier." These realizations are rare among undergraduate students outside of DTR yet critical for supporting student learning and progress-making in project-based learning environments [23].

### *Leadership and Teamwork*

Students reported developing leadership and teamwork skills. Over time, students got better at taking more ownership of their project and taking responsibility for their own trajectory and progress. Students felt responsible to their teammates and partners, and reported growing to be more accountable for their own actions. Students overwhelming felt that they learned to work more effectively with others in ways that helped them accomplish research goals and grow as individuals. One student noted: "having a team that was very open to collaboration was an extremely productive atmosphere. We were all able to leverage our strengths, but at the same time, we were also able to grow significantly in a variety of ways." Students reported struggling and then learning to find a space for themselves on their teams to strike a balance between taking over a project entirely and taking on an inconsequential role. One student commented: "Working on a team is not just about what you can get accomplished, but also about learning how to work better with others."

### *Failures and 'Meta-Blockers'*

Students were deeply reflective about their failures and areas where they wanted to continue growing. Many students reported struggles with different facets of regulation, including spending too much time with less important work, working without having a clear sense of their research goals, and being adamant in figuring things out alone without help. Students also identified a number of 'meta-blockers' that they felt prevented them from being more effective or growing in the ways they had desired. Students reported feeling a lack of confidence, having trouble focusing on tasks, being too hard on themselves, being reserved and not asking for help, struggling with uncertainty, and having tendencies to gravitate toward or shy away from technical work. In follow-up discussions with the faculty mentor, students developed strategies for learning to overcome their meta-blockers and continued to work on them with the support of their SIG lead and faculty mentor in subsequent quarters.

## Gains in self-efficacy and attitude shifts

Results from the pilot show significant shifts in students' attitudes and beliefs toward their ability to develop novel technologies and conduct research. One student noted that a highlight of DTR was that she actually finished a paper and submitted it to a conference. Another student noted that DTR "pushed [me] outside of my comfort zone in what I could do. [I realized] I was more capable than I thought I was." Students commented that DTR made something daunting doable: "For a long time, [I] hear people say [it's] ok to get in without knowing everything. [DTR] deeply ingrained that you can get started without having to be experienced."

Students reported that their DTR experience positively impacted their attitude toward academic research. Students report that despite research being "much more rigorous than [they] could have guessed," they became much more enthusiastic and found "the opportunity to actually drive new knowledge to be pretty exciting." One student wrote that DTR "was a great experience and has drastically shaped how I think about research and big picture problems.'' Students also commented that the experience "opens up career paths" and that "research in grad school seems less intimidating now."

We also observed significant shifts in students' attitudes on help-seeking and help-giving. For help-seeking, students who were initially reluctant to ask for help learned that "[they] can ask for help and that everyone asks for help and it doesn't make them stupid to need help." One student noted that she reached out more easily once she realized that "people in DTR could help me out much more than I could get by myself." For help-giving, students who initially dismissed their own abilities recognized that "there's always something [they] can help someone else with." Students also commented that they enjoyed giving help to others who needed it; they noted that helping others allowed them to "get a much better sense of what everyone else was doing" and usually gave them additional ideas that benefitted their own project and learning.

### Sense of Belonging in a Supportive Community

DTR students felt a strong sense of belonging in a supportive community of "friendly, talented, motivated, and caring" individuals. Students reported that seeing other people in DTR's "love for helping others" led them to want to cultivate and spread the helping culture by both "share [their] experience and utilize others." Students felt that they were in a community of "similarly motivated students who care about each other's work" and felt they could rely on this community in ways that they never had before. One student wrote: "DTR is a class but I do think it is more importantly a collaboration between all students. I have never been this close to other classmates and DTR makes it such a collaborative environment." Students made new friends and reported bonding outside of the classroom and research context.

## ANALYSIS OF COMMUNITY-BASED PROCESSES IN DTR

In this section, we analyze how the practices, structures, and tools of Agile Research Studios used in DTR may have helped to orchestrate learning and support students planning research work and overcoming challenges quickly with the support of peers. Our goal is to better understand the variety of community-based processes that may have contributed toward addressing the 1:X challenge.

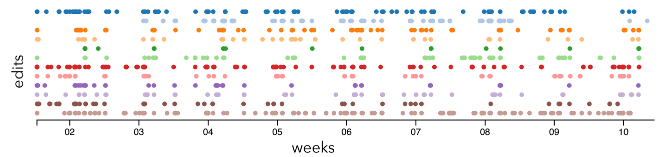


**Figure 6. Visualization of revisions to each team's sprint log across the weeks of the Winter 2016 DTR studio. Each row of colored dots presents the edits made by a team. Students planned a shortened 'sprint 0' in the first week; each subsequent 2-week sprint started and ended with SIG meetings scheduled 2-3 days after the start of each week.**

| | | -1D | SIG | +1D | Week |
|---|---|---|---|---|---|
| P(≥1 revision) | W16 | 88% | 62% | 35% | 75% |
| | F15 | 72% | 57% | 24% | 54% |
| # of revisions | W16 | 2.9 | 0.7 | 0.6 | 3.1 |
| | F15 | 1.6 | 0.7 | 0.4 | 1.7 |

**Figure 7. The likelihood and average number of sprint log revisions made by teams each week in the day before their SIG meeting (*-1D*), during their SIG meeting (*SIG*), the day following their SIG meeting (*+1D*), and throughout the rest of the week (*Week*).**

### Research Planning and Replanning

*How often did students plan, monitor, and replan their work?* Students updated their sprint logs regularly. In Fall 2015 when sprint logs were first introduced, student teams made an average of 4.4 revisions per week (515 revisions total). By Winter 2016, students made an average of 7.3 revisions per week (857 revisions total). Figure 6 shows that teams in Winter 2016 made edits to their sprint log throughout the week, and almost all teams made at least one edit each week.

Looking more closely at when students made edits, Figure 7 shows that while students made a majority of their edits throughout the week and in particular in the day prior to the SIG meeting, they also regularly made edits during the SIG meeting and the following day. In Winter 2016, on any given week 62% of student teams made edits during SIG meetings, and 35% of them made edits immediately after SIG meetings. This is consistent with our observations of students updating their sprint and adding resources based on feedback and suggestions from peers and mentors during SIG meetings, and of student teams meeting up after SIG meetings (sometimes immediately after) to sync up and replan their sprints to refocus immediate project goals.

*Did students form feasible plans and follow good practices?* Students were fairly accurate in estimating how long it would take to complete their sprints, but did have a general tendency to underestimate. Students' committed points were within 20% of students' reported work times on 70% of sprints (59 out of 84 sprints); students took even longer to finish their commitments 20% of the time (17 out of 84 sprints). To compensate for some stories taking longer than anticipated, students backlogged 23% of their tasks (468 out of 2,003 tasks) for completing in a future sprint.

| | N | Total | Median | Average | % of studio |
|---|---|---|---|---|---|
| Winter 2016 | 21 | 160 | 7 | 7.6 | 38% |
| Fall 2015 | 14 | 61 | 4 | 4.4 | 34% |
| Spring 2015 | 14 | 65 | 5 | 4.6 | 36% |
| Winter 2015 | 15 | 86 | 5 | 5.7 | 41% |
| Total/Average | 33 | 372 | 5 | 5.8 | 37% |

**Figure 8. Helping statistics showing the number of fulfilled help requests reported in different quarters of DTR, the average/median number of people receiving help, and the % of people in the studio receiving help.**

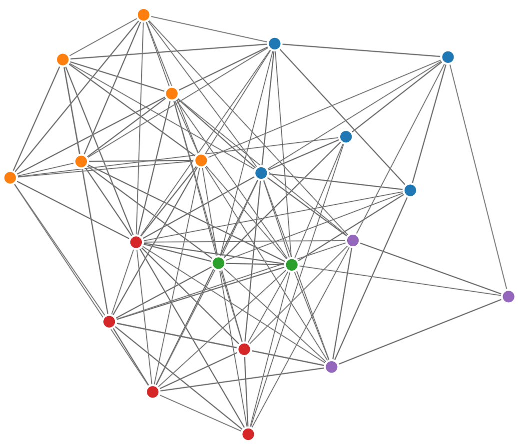

**Figure 9. Helping graph from Winter 2016. Each node represents a student and links represent fulfilled help requests. Students helped and received help from both students in their own SIG (same color node) and across the studio.**

Students followed a number of other planning practices recommended by faculty and graduate student mentors. Students were advised to stay within the points allotted for each sprint; in only 3 out of 84 sprints did students spend more hours than the recommended point allotment by more than 20%. Students were encouraged to identify resources that may help them complete stories on their sprint; in the 'helpful links' field on their sprint logs, students recorded 120 resources that they found or were suggested by peers and mentors (5.5 per team per quarter).

*How did SIGs and mentors support research planning?*
Students noted that SIG meetings and follow up discussions with faculty mentors and SIG leads helped them learn to better plan at appropriate fidelities, see the big picture and refocus on higher-level research goals, refine research directions and questions, and to better manage team issues. Students also report that talking to faculty mentors and SIG leads helped them to set appropriate expectations, and to reorient their perspective on research given frustrations and problems. As developing mentors, SIG leads expressed that they felt that they were able to help students drive their research, and expressed a desire to continue learning to more effectively manage young researchers.

### Help-seeking and Collaboration

*How willing were DTR students to help each other?*
DTR students helped over a third of the other students in their studio in any given quarter, and fulfilled 372 help requests over the four quarters in our dataset. See Figure 8 for the helping statistics from each quarter.

DTR students were willing to help others working on different projects in their SIG and across the studio; 329 reported help requests (89%) were fulfilled by a student working on a different project. 115 requests were fulfilled by a fellow SIG member working on a different project (31%), and 214 requests were fulfilled by a student in another SIG (58%). Figure 9 shows a dense network of helping behaviors from the Winter 2016 that connects students both within and across SIGs.

Despite high-connectivity across SIGs on average, some students primarily asked for help within their SIGs. They felt it was easier to ask for help from people they knew well, but also reported wanting to reach out beyond their SIGs in the future so as to offer help to more people, learn what others are working on, and get fresh perspectives on their own projects.

Both within SIGs and across the studio, students helped other students who also helped them in return. Of the 329 help requests made by students working on different projects, 196 requests were reciprocated in the same quarter (60%) and 231 requests were reciprocated across quarters (70%). Students also helped other students when they did not receive help in return. Many students expressed wanting to pay it forward, and felt that it was natural to want to help others given all the help they had received in the past. One student said "Nobody feels guilty receiving help because they know they've helped others as well."

*What kind of help did students provide?*
Students helped each other on a wide variety of requests across design ($n$ = 159), technology ($n$ = 129), and research ($n$ = 118). Figure 10 shows help requests across these areas by category. Popular requests include asking others to test the latest version of a prototype, helping with web/mobile development (e.g., building a Chrome extension or deploying an iOS app); and refining research directions. Help across requests for design, technology, and research were fulfilled by team, SIG, and studio members at about the same proportions. Among larger subcategories, there were two instances where more help was provided by one group than another. This includes help on research directions, where 34 of the 41 requests were fulfilled within a SIG (84%), and for prototype testing, where 72 out of 103 requests were fulfilled by studio members across SIGs (70%). These numbers are consistent with ARS structuring SIGs around particular areas of research focus, and show students reaching more testers by recruiting helpers across the studio.

*How was help dispersed across the community?*
In total, 60% of the help requests (223 out of 372) included at least one out of the six most senior students in DTR (3 PhD students, 3 senior undergraduates) as a helper or as someone receiving help, see Figure 11. The most senior students helped on 41% of help requests; PhD students were disportionately more likely to help with research (48%) and technology (44%) than design (19%); senior undergraduates were also more likely to help with research (44%). The most

| Design help (n=159) | | Technology help (n=129) | | Research help (n=118) | |
|---|---|---|---|---|---|
| PROTOTYPE TESTING | 103 | WEB/MOBILE DEV | 81 | RESEARCH DIRECTION | 41 |
| NEEDFINDING | 45 | SYSTEM FEATURES | 20 | STUDY DESIGN | 33 |
| BRAINSTORMING | 15 | DEBUGGING | 17 | PAPER WRITING | 32 |
| FEEDBACK | 16 | PAIR PROGRAMMING | 14 | DATA ANALYSIS | 15 |
| INTERACTION DESIGN | 16 | ARCHITECTURE | 12 | GRANTS | 14 |
| UI/UX DESIGN | 9 | GENERAL | 10 | USER STUDIES | 10 |
| RECRUITING | 8 | DEV TOOLS | 7 | RELATED WORK | 9 |
| PROTOTYPE DESIGN | 4 | ALGORITHMS | 3 | | |

**Figure 10. Fulfilled help requests by category.**

| | N | Total | Design | Technology | Research |
|---|---|---|---|---|---|
| Providing Help | | | | | |
| PhD students | 3 | 73 (20%) | 19% | 44% | 48% |
| Senior Undergrads | 3 | 81 (22%) | 36% | 27% | 44% |
| Receiving Help | | | | | |
| PhD Students | 3 | 59 (16%) | 42% | 19% | 14% |
| Senior Undergrads | 3 | 53 (14%) | 34% | 38% | 42% |

**Figure 11. Helping statistics for the six most senior students in DTR.**

senior students received help on 30% of help requests; graduate students disportionately received help with design (42%) over tech (19%) and research (14%), and senior undergraduates received more help with research (42% of the time). This implies that while senior undergraduates were helping others with research, they themselves were also still receiving significant research help from other students, more so than graduate students were.

The other 40% of help requests (149 out of 372) did not involve the most senior students. Among these, there was more help requested and fulfilled in design (55%) and technology (37%) than in research (23%). This suggests that while the less senior students were able to help each other on a significant number of requests, they still looked more to the most senior students and the faculty mentor for research help.

*How did studio meetings support learning from others?*

Students reported that studio meetings helped them learn from other students in the studio and broadened their perspective on their own projects and on research more generally. Students noted that demo-critique sessions helped them brainstorm new ideas, clarify research directions, and gain fresh perspectives. Students benefitted from pair research and found it to be a "fantastic way to scale a class where a professor doesn't have time/specific skills to give each student that much individual attention, and when students can help each other." Students also found that the learning modules led by SIG leads and faculty mentors helped stretch their thinking, for example to consider validity concerns when designing a study, architecting apps that can scale to millions of users, and understanding realistic research timelines and the need to plan for failure.

### Community Connection

DTR members communicated extensively with one another outside of in-person meetings via Slack. Over a six-month period, DTR members sent a total of 36,919 messages and shared 660 files. Of these messages, 8,407 of them (23%) are in visible public and private channels the authors are a part of; the rest of the messages are direct messages or other private group conversations.

| | | |
|---|---|---|
| Channels | 8403 (100%) | |
| Team | 4948 (59%) | project discussion among teammates (and w/ mentors) |
| Studio | 1131 (13%) | studio-wide announcements and water cooler discussion |
| Bot | 1063 (13%) | GIT (code) and Youtube integration (sprint videos) |
| Community | 416 (5%) | swag, senior gifts, 20% time, job search, fun activities |
| SIG | 305 (4%) | sharing resources and communicating within a SIG |
| Faculty | 240 (3%) | faculty discussion about agile research studios |
| Interview | 211 (3%) | committee coordinating and scheduling DTR interviews |
| SIG Heads | 71 (1%) | SIG head and faculty check-in |
| Other | 23 (<1%) | occasional use; testing bots |

**Figure 12. Slack channels and message counts by group and purpose.**

Figure 12 shows the number of messages sent through visible channels categorized by purpose and the members who participate in them. Among channels that mapped onto the social structures described in the Agile Research Studios model, we observe that 59% of these messages were in team channels, in which students planned their work, shared their progress, asked questions to teammates and mentors, and worked collaboratively on technical problems and research tasks. Another 13% of messages were sent in channels joined by all studio members, through which students and faculty sent announcements, made studio-wide requests for help, posted interesting links, and had 'water cooler' conversations over a wide range of topics. Fewer messages were sent in SIG channels (4%). One possible explanation is that, given the frequency in which these members met in person and how well they got to know each other over time, SIG members may have felt comfortable enough to reach out to specific other SIG members and their SIG leads over direct message.

Students and faculty formed other channels to support a variety of community goals. 13% of messages were posted in integrated bot channels, e.g., that showed code commits through Github across teams. These channels supported social translucence by making student work progress visible to other students [22], and allowed mentors to get a sense of what students are working on at a glance. 5% of messages were sent in special community-building channels, in which students designed DTR shirts, prepared senior gifts, discussed 20% time projects, helped each other with job search, and planned fun community activities. Another 3% of messages were sent in the interview committee channel, where committee members coordinated, scheduled, and prepared for interviewing prospective DTR students.

Individual requests for help can quickly spur others to offer their help, and also to seek help themselves. Figure 13 shows a conversation in the Water Cooler channel with students requesting, offering, and trading help to test their latest prototypes. An initial request for help is responded to within minutes, and spurred a 'helping party' in which six students agreed to test for each other across four projects. While help requests don't always spur this degree of Slack activity, we observed that help requests are often responded to within minutes. DTR students generally felt that if they ask for help, they will receive it from the DTR community. They reported reaching out to people on Slack whenever they were stuck and not being afraid to direct message other people in DTR they didn't know well to ask random questions.

### DISCUSSION

In summary, our pilot study of DTR showed that the practices, structures, and tools of an Agile Research Studio empowered

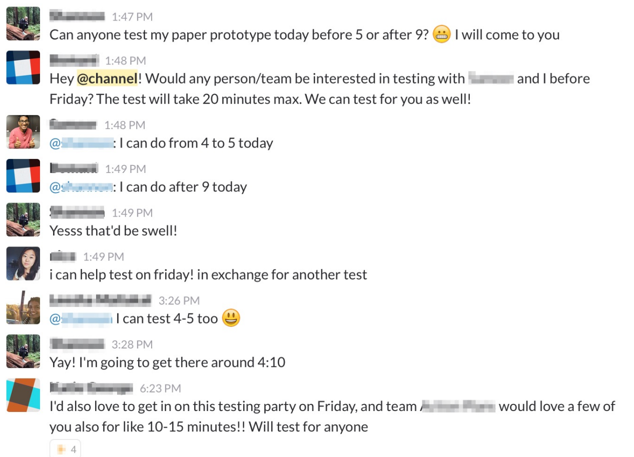


**Figure 13. A conversation in the Water Cooler with students requesting, offering, and trading help to test their latest prototypes.**

undergraduate students to plan research work at weekly intervals and overcome challenges quickly with the support of peers and mentors. This allowed them to conduct independent STEM research along a faculty member's core research directions, as would be possible through dedicated 1-on-1 apprenticeship with faculty members but at just a fraction of the time required to support a much larger research learning community than would be traditionally feasible. We discuss below the implications of our findings, the limitations of our study, and areas for continued work.

### Advantages of ARS over Traditional Research Training

DTR illustrates some of the advantages of adopting Agile Research Studios over traditional methods of orchestrating research training. For undergraduate students, participation in DTR led to self-reported gains in design, technology, and research skills, increases in innovation self-efficacy, and gains in self- and shared- regulation skills. For graduate students, DTR provided authentic practice in mentoring and gave them an opportunity to learn to lead their own research group. For the junior faculty mentor, DTR greatly expanded the breadth and depth of their research program despite having similar time and resource constraints as other junior faculty. All members of DTR benefit from working with and learning from a supportive community of others.

### Bridging Cooperative Work and Authentic Learning

ARS provides a powerful example of how socio-technical systems can be designed to support cooperative work in ways that also allow us to provide authentic learning experiences to increased numbers of students. Socio-technical support for mentoring self-directed learners, leveraging distributed expertise, and promoting awareness of needs reduces orchestration burdens to scale mentor time while engaging students in authentic practice [42] to produce effective work outcomes. We believe socio-technical solutions for supporting cooperative work will play an increasingly important role in empowering us to provide authentic learning experiences to many more students to prepare them for tackling complex challenges in the 21st century [46].

### Study Limitations

*Not Directly Measuring Learning*

Our study did not provide directly measures of student learning and the growth in their regulation skills over time. Instead, we made use of student self-assessments that surfaced students' perceptions of their learning and growth, which could be biased as students may under- or overstate their learning and skills. Consistent with design-based research best practices [3, 21], we use these initial measures to quickly identify failures and to iterate, and will follow with more rigorous measures as designs show promise. To complement these initial measures, we also collected and analyzed traces of student interactions with one another and with the virtual studio tools; this provided evidence that students were following regulatory processes and being mentored to follow it better. Prior research shows that the practice and mentoring of regulation skills helped students develop them in a number of science domains [1]; future work can attempt to measure such gains directly in DTR.

*Not Establishing Sufficient Conditions for the Model*

While our analyses provide evidence that the ARS model led to the observed outcomes, one study is not sufficient to isolate all the factors necessary to DTR's success. As one example, while we observed that DTR students felt a strong sense of belonging in a supportive community, we cannot say at this point that adopting the ARS model as described is sufficient for creating a strong community culture in which people care about one another and are as willing to help as DTR students were. We look forward to refining the ARS model over time as we continue to develop our understanding of other design considerations that may be critical to a studio's success.

*Intervention was Implemented by an Author*

Design-based research allows researchers the control to simultaneously iterate on and study complex models. However, it also introduces the possibility of bias as one of the researchers was also the faculty member in the design. To limit the risks of biasing results, we centered our analysis primarily on student self-reports and log data. While student self-reports may still be biased in favor of the desired learning outcomes, students were also forthcoming about their struggles with regulation. In future work we are interested in supporting other research communities adopting the ARS model and studying its effectiveness and any adoption challenges across sites.

*Participant Selection is Responsible for Observed Results*

While we have argued that the ARS model as a whole led to the observed outcomes, an alternative explanation is that the results can be primarily attributed to the selection of students in DTR. While we believe the selection of participants to be an important part of the ARS model, this alternative explanation is unlikely because (a) even the best undergraduate students typically require significant mentoring to learn to conduct research; (b) DTR students attributed their learning and work outcomes to other components of the ARS model in self-reports; (c) through design-based research we introduced components that form the current ARS model based on shortcomings we had observed in previous iterations. Still, future studies can seek to better understand how student selection affects ARS outcomes and refine the model accordingly.

### Ongoing Research Directions

One area of continuing research is to design better tools for supporting students learning regulation skills and becoming aware of needs for mentoring and support. For planning, learners still lack scaffolds for planning effectively on their own and can struggle to reprioritize tasks to deliver research value and fail to recognize their needs for help. For help-seeking, while students use Slack extensively outside of in-person meetings, they still struggle with formulating help-requests, especially for more open-ended help on topics such as framing design arguments or refining research directions. We are in the process of developing a set of new virtual studio tools that provide more scaffolding for sprint planning and that provide additional support for connecting students to available mentors and peers who are best able to help them.

We are also interested in understanding the extent to which the ARS model can increase participation in authentic research experiences, both for DTR and across other research sites and contexts. In DTR we currently have a studio of about 20 students; how many more students can we support? What tradeoffs may we incur and what conditions, practices, structures, and tools may we need to support a larger community, should it even be desirable? Outside of DTR, we are interested in addressing challenges in adopting the ARS model given variations at different sites, and supporting others who wish to adopt the model to adapt it to fit their goals, resources, and constraints. We look forward to these possibilities and the opportunity to continue improving all of our research communities to support our training and work goals.

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