Enabling a Classroom Design Studio with a Collaborative Sketch Design Tool

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Abstract—The use of a studio approach—a hands-on teaching method that emphasizes in-class discussion and activities—is becoming an increasingly accepted method of teaching within software engineering. In such studios, emphasis is placed not only on the artifacts to be produced, but also on the process used to arrive at those artifacts. In this paper, we introduce Calico, a sketch-based collaborative software design tool, and discuss how it supports the delivery of a studio approach to software design education. We particularly describe our experiences with Calico in Software Design I, a course aimed at introducing students to the early, creative phases of software design. Our results show that Calico enabled students to work effectively in teams on their design problems, quickly developing, refining, and evaluating their designs.

Index Terms—Software design studio, sketching, design, Calico

I. INTRODUCTION

Design studios are an increasingly popular approach to teaching topics such as software architecture [10], human computer interaction [9, 20, 26], and software engineering [12, 24]. In a design studio, instructors provide guidance in the moment of working, rather than simply evaluating a separately created final product of the students’ work. Students learn how to reflect on their experiences, collaborate within teams, and learn from one another, all under the guidance of an experienced instructor. Studies have reported effective results in using design studios to provide students with opportunities to put the knowledge gained from lectures into practice [11].

Particularly within software engineering, there are methodologies and techniques that are difficult to impart in a traditional classroom setting. Typically, when it comes to software design, an overarching focus exists on the design artifact itself, as well as the patterns and notations in which this design artifact is to be captured. However, much less is said about the processes through which the design is ultimately produced. In response, various experiments have been performed introducing the design studio approach in software engineering courses [2].

While effective, there are a number of challenges instructors face in successfully employing a design studio approach. Unlike real world studios, students often do not have dedicated spaces in which to work, making it challenging for them to continue their work from one class to the next. Further, student teams must use the facilities available, which may be inadequate for sharing and discussing designs as the size of the class grows. Finally, helping students to organize and edit their designs is a core part of the design studio approach, but is often inadequately supported by traditional sketching mediums.

To address these issues, we have deployed a collaborative sketch-based design tool, Calico, in the studio sessions of our software design course. Calico provides four main aspects that enable design studios: (1) a shared set of drawing canvases that persist across classes and are accessible through both slates and personal computers, (2) a fixed seven-by-seven grid of canvases to organize work and collaborative effort, (3) scraps, allowing elements to be manipulated, moved, resized, and rotated, and (4) a palette, supporting the creation of reusable content that is available across different canvases in the grid through a global clipboard for scraps.

In this paper, we present our experiences in using Calico to support design studios within the Software Design I course at UC Irvine. The rest of this paper is organized as follows. Section II reviews relevant background material pertaining to the use of design studios in software engineering education and the tools that exist to support it. Section III summarizes the design studio course taught at UC Irvine, its pedagogical foundation, and reviews Calico. Section IV presents the quantitative and qualitative findings of our evaluation of the delivery of the design studio using Calico with respect to how the students carried out their design, as well as how they collaborated using Calico. Lastly, we discuss insights from our evaluation in Section V and conclude with an outlook at our future work in Section VI.

II. BACKGROUND

The studio method of education has long been practiced in design-centric disciplines such as building architecture [15]. Educators in software engineering have begun to adopt this approach into their own curriculum, with repeated success (e.g., [9, 12, 20, 24]). Kuhn, for example, adopted the practice from architecture pedagogy and promoted six practices in her own design studios: (1) beginning projects with complex, open-ended questions, (2) rapid iterations of design solutions, (3) a culture of critique, (4) discussing heterogeneous issues, (5) challenging the design with constraints, and (6) using a variety of design media [12].
According to Reimer and Douglas, design studios are valuable to students because they learn best by doing, can use teachers as resources, and learn from their peers through design crits, in which designs are critiqued across iterations [20]. Many researchers (e.g., [11-12, 20, 22]) see the design crit as the cornerstone of the design studio, which builds on Donald Schön’s observation that individuals can learn by reflecting on the implicit actions that they take in practice [22].

While the design studio approach is increasingly being used to teach software engineers, only a handful of tools exist that could potentially be used to support the students within a design studio environment. These tools include Classroom Presenter [1], Ubiquitous Presenter [25], and DyKnow [4]. Such tools are primarily designed to increase student participation by sharing worksheets that the students can submit, or allowing students to write on the instructor’s lecture slides while they are being presented. As such, they are helpful in facilitating interactions with the instructor, but are not designed for direct interaction among groups of students working with a shared artifact.

Another approach has been to bring tablet PCs into the classroom, allowing sketches made in drawing programs to be shared through tools such as configuration management systems [24]. This enables students to share and maintain their sketches, but unfortunately, is too slow of an approach to support co-located, rapid collaborative work. Particularly, committing and checking out sketches introduces a high overhead that interrupts the flow of the work. Other collaborative design tools, such as GAMBIT [21], enable designers to sketch together, but they have not been evaluated in a classroom setting.

### III. THE COURSE

The “Software Design I” course at UC Irvine is part one of a two-part series that introduces students to the thought processes and practices of professional software designers [2]. Overall, the two-part series provides students with a broad perspective on software design, aiming to equip students with a host of design techniques that they can apply to different software design problems. A particularly distinguishing feature of the course series is that it does not talk about the design of code, but also about the design of applications overall: what functionality they should have, what their underlying architectures should be, and, of course, what their code structure should be. The courses achieve this by focusing on design activities, such as sketching, storyboarding, architecting, simulating, generating alternatives, and others, and afford students an opportunity to practice these activities in the context of non-trivial, realistic design problems.

This material is partitioned over the two courses by treating design as a continuum from “early design”, when the designer has little to go on and must design the application as a whole, to “late” design, when much of the functionality is set but the details of the code must still be decided. The first course focuses on early design and the second on late design, while recognizing that neither can be done in isolation. In the remainder, we exclusively draw upon the first course in the sequence.

#### A. Design Studios

Software Design I employs a design studio approach. Building on lectures which introduce suitable theoretical perspectives, a significant part of the course is spent with students practicing design in class, using different techniques at different times. Studios focus, for example, on generating ideas (brainstorming), identifying tradeoffs, mind mapping, sketching, silent interactions through sticky notes (to balance team input), and identifying stakeholders and their possible needs and constraints. By performing these activities live in class, there is a significant opportunity for the instructor to observe, steer, and intervene as necessary. In addition, students are much more focused, and willing to share their work, ideas, and approaches with each other as part of the learning experience. More importantly, the design activity becomes one of iteration and improvement. Whereas “at home” design often leads to a single design that is handed in, the design studio lends itself to focusing on the intermediate steps necessary, why they are necessary, and how students should structure their approach.

The inspiration for our design studios stems from the activities that we have seen professional designers employ. We have talked with software designers at a broad range of software development organizations, have taken many pictures of their work, and, in the context of a National Science Foundation workshop [19], captured video of them at work. In analyzing this body of work, as well as related literature [3, 5-6, 8, 18], we settled our design studios on six key lessons that we want the students to always be aware of and use:

- Explore both the design problem and solution together.
- Select appropriate guiding design principles.
- Create and compare many partial alternatives.
- Abort or change ineffective design paths.
- Select appropriate media in which to explore, record, and present design ideas.
- Use others’ previously used approaches and solutions.

In other words, we want students to consistently employ a designerly [6] mentality and approach and engage with design problems and their solutions in a great amount of depth. After all, cursory explorations rarely reveal all aspects of the design complexities at hand; the devil is in the details and we want our students to know how to reach those details.

Whereas later in the quarter we expect students to know how to apply those lessons by selecting the appropriate design strategies and techniques at the appropriate times, early in the quarter we more explicitly guide the students. In one studio, for instance, we ask the students to watch a video of software designers at work on a traffic signal simulation problem and identify some of the key design decisions they made. We follow this with a homework in which students individually think about the problem and an in-class group exercise where they bring their thoughts together, beginning the process of...
creating a final design, which they work out as a team over several lectures.

B. Enabling Design Studios with Calico

In each of the in-class design studios, we gave student teams a set of tablets with the Calico software, and instructed teams on how to load Calico onto their own machines. The Calico tool itself is a sketch-based software design environment that was developed to support the early stages of software design. A full description of the tool is available elsewhere [16-17]. We briefly summarize its features here as they pertain to its use in our design studios.

First, Calico operates as a regular, synchronous drawing canvas that is shared among all members of the group, as in the left of Fig. 1. Students can draw, erase, redo, and change pen color – just as they could when working on a piece of paper. As we describe next, Calico offers much richer functionality, but “out of the box” this basic functionality always works and students could choose to ignore the advanced functionality until they need it. This is important for two reasons. First, it reduces the hurdle to participate, enabling all team members to join the studio quickly. Second, it preserves an important behavior seen in design: mixing and matching content at various levels of formality [18].

Second, scraps enable students to manipulate and interact with pieces of their sketches. Scraps are objects, similar to patches of paper, that group content within a user-defined space, allowing users to interact with sketches in ways beyond just drawing and erasing. Like patches of paper, scraps can be moved, stacked, and organized, as well as rotated, resized, copied, and related with connectors (arrows that stick). Taking on the shape of the pen stroke that create them, scraps are inherently flexible in what they can represent. For instance, students can use scraps to model basic UI elements such as buttons or dialogs, and subsequently use these to quickly organize them into a first proposed design. Upon reflecting on this first design, they can make improvements simply by adding scraps, moving them around, resizing them, etc., to improve the layout of the proposed user interface. Fig. 1 is an example where the scraps represent a user interface for which scraps of various sizes have been composed into a comprehensive inter-

Other kinds of diagrams, such as architectures, UML diagrams, or entity-relationship diagrams, can similarly be modeled and manipulated through the use of scraps [17].

Third, a palette assists in rapidly building a library of design building blocks, which is shared among group members. Users may add scraps to the palette, allowing other students to reuse them by dragging one onto the canvas and drawing on top of it like a template.

Fourth, a grid facilitates the organization of designs. Calico provides multiple work areas, called canvases, that the user may access. While viewing any canvas within Calico, the user can zoom out to see the seven-by-seven grid of canvases available to them (right of Fig. 1). This provides designers with the space to explore several solutions simultaneously, without having to erase work to make room for new ideas as they might do on a whiteboard. Moreover, it allows them to partition work among canvases (a user interface in one cell, an architecture in another, a component worked out in detail in another, etc.).

In addition to providing multiple canvases, Calico’s grid supports the copying of one canvas to another, allowing designers to quickly derive multiple alternative solutions from a single point of inspiration while preserving the state of the original canvas. This is a useful feature for an individual but becomes more valuable when working with a team, as it now is trivial for different students to explore alternative next steps.

The grid and its content are shared by all users that connect to a common Calico server. This enables students to either work synchronously—by working in the same canvas – or asynchronously—by working in different canvases. The occupants of a canvas are visible in the grid perspective, giving users awareness of the surrounding activities and who is working where on the design. The grid is accessible to anyone who can connect to the server over the network, making access possible both in between and across classroom sessions.

Fifth, the highlighter feature of Calico helps teams explore and discuss designs together, without interfering with the content of the canvas. When using the highlighter, a large, highly visible stroke appears on the canvas only to fade away after several seconds, leaving the canvas unaltered. This becomes useful when attempting to explain something about a
design to another student, or when performing critiques of a design artifact (as an instructor or another student team might do). Sequences of highlights, too, can simulate a design “in action”, for instance, drawing arrows to where in the design data flows during an execution or simulate the usage of a user interface.

C. Design Studio Projects

In the fall quarter of 2012, the Software Design I course used Calico to support two software design projects that each spanned about two weeks, and each involved two full classes (all classes were taught by the last author of this paper). For each class, the desks were arranged into a circle to promote group interaction during the design studios. Prior to the design studios, students were given a one hour Calico information and training session to acquaint them with the tool. In both design studio projects, students were separated into groups of 6-7, each group receiving 2-3 tablet PCs with the Calico client installed to be shared among the group members. Previously set up Calico servers were then assigned to each group, providing each with a unique, persistent workspace. Because the number of students per group exceeded the number of tablets they received, the students had the option of using personal laptops to connect to their group’s server.

In the first class period of the first design studio project, students were asked to design a “virtual campus visit” which could be used to advertise a university and its exciting ongoing activities. For this task, students were challenged to create three unique design alternatives. In the subsequent class period, two days later, students were tasked to create one final design from the three design alternatives. Students were permitted to use paper, but were asked to deliver their designs in Calico.

In the second design studio project, students were tasked with creating an educational traffic signal simulator for an urban design course. As a prior assignment, students were asked to watch videos of professional software designers working on the same design problem [19]. In the first class period, half of the teams were asked to design the software architecture of the system, and the other half the user interface. In the second class period, two days later, the teams were rearranged so teams were composed of an even split between members that created the user interface and those that created a software architecture. They then were asked to create one final cohesive design with both parts. As with the first activity, students could use paper, but were asked to deliver the final design in Calico.

IV. MEASUREMENTS AND QUALITATIVE OBSERVATIONS

True to the nature of a design studio, students engaged in a significant amount of designing, often through discussion, writing, and sketching. While some students chose to participate by talking or taking notes on paper, the majority of students carried out their design using Calico. Fig. 2 shows an aggregated summary of all Calico activity as a function of time during all four studio design sessions, with each studio lasting approximately eighty minutes.

The aggregated measure represents all activity related to using the tool, where the peaks represent drawing or the usage of scraps, and the valleys are moments of discussion and reflection. In the first design studio (Fig. 2a), it was common to see teams break into subgroups that independently worked on one of the three required design alternatives. Halfway through,
however, the design teams began to engage in much more discussion, which is represented by the reduced activity (as indicated by the pattern in Fig 2a). During the second session of studio I (Fig. 2b), the students merged the alternative designs from the previous class, which led to much more discussion of the design. Teams often had at least one member documenting design decisions, which is visible as spikes in activity.

In the second design studio, students were challenged with a much more complex problem, involving either a software architecture or user interface component, leading to more discussion than with the first design problem. The final design session required students to merge design solutions of heterogeneous types, which involved frequent bursts of copying, and lulls in activity where significant discussion took place.

At the end of the final design studio, we administered a technology acceptance model (TAM [7]) survey on usefulness in order to collect feedback from the students, with the questions presented in Table 1. We received feedback from all 54 students in the class. Overall, the students responded favorably to Calico, rating it at 5.28 out of 7 in usefulness. Many students reported difficulty in using some of the technology, such as scraps, which is unsurprising given their relative unfamiliarity with the tool. Most reported that the collaborative nature of the tool was its strongest quality.

<table>
<thead>
<tr>
<th>Question</th>
<th>Average</th>
<th>St Dev.</th>
</tr>
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<tbody>
<tr>
<td>Using Calico improves the quality of the work I do</td>
<td>5.22</td>
<td>0.93</td>
</tr>
<tr>
<td>Using Calico gives me greater control over my work</td>
<td>4.80</td>
<td>1.31</td>
</tr>
<tr>
<td>Calico enables me to accomplish tasks more quickly</td>
<td>5.00</td>
<td>1.32</td>
</tr>
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<td>Calico supports critical aspects of the design activity</td>
<td>5.20</td>
<td>1.04</td>
</tr>
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<td>Calico increases my productivity</td>
<td>5.12</td>
<td>1.08</td>
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<td>Calico improves my performance as a designer</td>
<td>4.82</td>
<td>1.44</td>
</tr>
<tr>
<td>Calico allows me to accomplish more work than would otherwise be possible</td>
<td>4.40</td>
<td>1.47</td>
</tr>
<tr>
<td>Calico enhances my effectiveness while designing</td>
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<td>1.16</td>
</tr>
<tr>
<td>Calico makes it easier to create my designs</td>
<td>4.92</td>
<td>1.17</td>
</tr>
<tr>
<td>Overall, I find Calico useful in creating my designs</td>
<td>5.28</td>
<td>1.05</td>
</tr>
</tbody>
</table>

A. Design Activity

We now examine how Calico was used in the design activities of the student teams, including brainstorming, organizing partial designs, refining solutions, and other activities.

1) Brainstorming: Students used collaborative brainstorming as the primary idea generation technique to develop the basis of their early designs. While every group approached this task in slightly different ways based on their group dynamics and experience, brainstorming was generally done in one of four ways.

First, many groups began discussing their design and taking notes primarily through exploring lists of requirements, stakeholders, and/or needs (as in Fig. 3, for example). These lists were made up of a combination of handwritten and text scrap notes, which were created on a single Calico canvas that all group members actively viewed and edited. Since the notes were readily available for each group member to view, contribute to, or change, the students used the shared notes not only as documentation for reflection, but also as a springboard for additional brainstorming ideas. Because of this, the content of the canvas transcended from being just an artifact of the discussion, to becoming central to the discussion itself. The visibility of the notes made it easy to think of related items that were not yet considered, without requiring the discussion to turn specifically to reviewing the notes. This appeared to create a fluid transition from the brainstorming phase into further design.

Second, some groups brainstormed by sketching parts of a user interface (Fig. 4). With this approach, students would also begin discussing the design, but instead of lists of requirements and stakeholders, the groups focused on interactions and user visualizations. While the discussions did include stakeholders (primarily as intended users), the focus was initially on the interactions they wanted to provide the user. Often, multiple conceptual sketches were quickly drawn to mock up aspects of the interface serving as an example of what the creator envisioned and illustrating a multitude of design decisions, both intended and assumed. Many of the sketches created during this time period required a lot of explanation and exploration, even by the creator, to fully grasp the design decisions and assumptions therein. Some ideas were not fully realized until an alternative was suggested, spurring the creator to articulate the reasoning behind their initial decision. For the groups taking this approach, transitioning to further stages of design seemed fluid as they took aspects of one or more concept sketches and began to develop additional design ideas to work out their design in more detail. Other groups taking this approach found themselves needing to discuss what types of users they wanted to support and what features they needed to provide before progressing too far beyond the concept sketches.

Third, we observed a few groups begin their work by exploring use cases, sketching the scenarios and situations in...
Fig. 4. Students use interface sketching to facilitate brainstorming.

Fig. 5. Student brainstorming by sketching scenarios.

which their design might be used (Fig. 5). This included sketches such as human figures arriving at a campus and needing to find event locations or go on a tour. These sketches served not only as a jumping off point for discussion of the use case, but also encouraged other use cases to be explored. Interestingly, one group took to this approach heavily, even requesting the sketch creator to "...draw faster so we can see a first person view too." These drawings, and subsequent designs, were all created using Calico. One interesting phenomenon we observed in this approach was that students were often found to be peering onto the creator’s tablet (as one might do in an art studio), rather than viewing the contents of the canvas on their own clients. Onlookers would discuss their own sketches, but peer onto the other people’s tablets to note the progress of the next sketch rather than to review the actual content of the sketch. When the new sketch was complete, or nearing completion, group members would bring it up on their clients to discuss it. It was this process of “sketch then discussion” that lead into the next stages of design and was done for each sketch in turn, until three satisfactory alternatives had been settled upon.

Fourth, one group opted not to use a shared canvas for their brainstorming, favoring a single student taking notes on paper (this happened once out of 16 groups total). While we will not compare the efficacy of brainstorming in Calico with paper here, our observations demonstrate Calico’s association with more democratized participation (see Section B. Collaboration).

2) Organizing content: Calico’s fixed spatial layout of the grid constrained how students could arrange their work. The rows and columns provided the students an opportunity for a structured layout of the designs. Each group came to an organization that was slightly different, but it was apparent in each group that there was thought placed into where work would be done. For instance, one organizational approach settled on by multiple groups was to assign rows to each design where the high level design was in the first (left most) column and further details of the design, or its parts, were on subsequent columns on the same row. An equally structured approach was to have each column represent a single visualization of the interface, allowing the users to step through the canvases, column by column, to view a storyboard of the user interaction.

Further, canvases in the grid always remained at the position where students manually placed them. This helps mitigate what is called the neighbor knowledge awareness problem [8], in which information that is associated with a design artifact and which might be needed in the context of multiple artifacts is only captured in one location and may not be recalled when these other locations are examined.

3) Refinement of solutions: Designs often need to go through multiple stages of refinement in order to get from a vague idea to what eventually will be a blueprint for implementation. In the context of our course, this refinement consists primarily of forming an idea, sketching it, and working with it until a reasonably detailed design is achieved. While the students do not get as far as a fully detailed blueprint for implementation, refinement and iteration on their designs is crucial to the learning process.

The refinement process followed by the students frequently focused simply on adding to an already existing design. The
students first created rough sketches that were used to communicate a concept, an example of which can be seen in Fig. 7a. If these preliminary concepts got adopted as an idea the group wanted to pursue further, additional time was spent on the canvas further detailing the sketch. It is through this process of reworking, as well as the addition of UI elements such as buttons or menus, that the refinement can be seen. Other types of refinement included the addition of arrows signifying relationships between objects or as indicators of transitions from one state to another.

Some groups took the process beyond the additive behaviors focused on a single canvas. They would redraw an entire design anew with a more structured approach, using a new canvas and a multitude of quite detailed scraps to precisely define the layout, areas, and elements within their interface (i.e., Fig. 7b is a redrawn and more detailed version of Fig. 7a).

Students made use of scraps to modify and copy parts of their design, which allowed them to quickly create new combinations of elements and arrangements for evaluation. This manipulation of content, including moving, resizing, rotating, and duplicating scraps (both individually and as sets of them together) supported the rapid evolution of the designs as multiple changes were made in quick succession.

Leveraging content already created by defining templates to be used as the basis of, or building blocks for, further designs allowed the students to reduce the work needed to explore alternatives. One way that the teams created templates was to create scraps and add them to the palette. Group members then pulled these scraps from the palette and applied them to the design on which they were working. One example of this was the creation of a fairly complex sketch of a human figure which was originally drawn in conjunction with a scenario the group was working on. The human figure sketch was made into a scrap and placed on the palette. The scrap was later used by the student to populate not only the same scenario, but all subsequent scenarios as well. As the student stated, they “just began spawning a bunch of people” by dragging them from the palette onto the canvas as needed.

Students additionally created templates by copying the entirety of one canvas to another, empty canvas. When this type of templating involved canvases with highly detailed designs, it allowed students to deeply explore alternatives while leaving the initial design unchanged. One group utilized this type of templating by designating a single canvas as the basis for all future designs. This template defined portions of the design – screen areas – upon which the group had made a decision, and served as a starting point for further development. Both methods of template creation allowed students to quickly reuse existing content, streamlining the process of content creation.

4) Evaluating alternatives: Designers often evaluate alternatives in order to select the one that best suits their needs. While professional designers are well practiced in this process [14], students often require more explanation and visualization of each alternative in order to understand the ramifications of their selections.

Scraps allowed students to visibly evaluate the effect of small changes in the layout or organization on a design. As discussed in the previous section, these changes were often made incrementally, by changing the placement, size, rotation, or number of scraps representing interface elements. Each manipulation creates a small but important alternative to the current design, allowing groups to quickly evaluate the alternative and accept the new version or reject it in favor of the original. To reject changes, students used the undo button or simply returned the modified scraps to their original positions, size, and/or rotations, allowing students to quickly return the design to its previous state.

The evaluation of entire designs, including comparing and contrasting them with alternatives, became a focus for each group. This activity often required stepping through each design and deciding what design decisions are valuable to include in a final design. Some groups selected one design they felt was the best and began refining it into their final design while other teams decided to begin the design of a new alternative based on what they learned from the previous three. For most groups this process included selecting elements from two or more designs and merging and morphing them into a coherent whole.

5) Reflecting on designs: After working on their designs for a time, students often took a proverbial step back to reflect on their work. This process occurred at various times throughout the design session, for instance when an individual felt they had completed their work, or when a sub-group considered their alternative to be complete. Many students retreated to Calico’s grid view, using its bird’s eye view to assess where they were in the overall process. Some opted for a more
detailed view of the work, quickly reviewing each of the cells in turn to verify that their sketched designs adhered to where their thinking had evolved.

B. Collaboration

In this section, we examine how Calico was used to support the collaborative nature of the design process.

1) Supporting spontaneous sub-group compositions: During the design sessions students fluidly transitioned back and forth between working as a group, working in sub-groups, and working alone. As the first task of the first design studio began, for instance, most groups divided into three sub-groups, each developing one of the three required alternate designs. Each sub-group worked on its own design, often isolating itself from the other designs in an attempt to create a unique solution. Students within the sub-groups claimed distinct areas in which to work or transitioned onto their own canvases for individual work. After spending some time working separately, these sub-groups and individuals began to be drawn to the activity of others. Often, what was once an individual working within their own canvas, became two, then three or four discussing and reworking the content. A student offered this example: "If something seemed interesting or if there was a bunch of people in one cell, I would jump in to see what was going on."

Spontaneous collaboration sparked discussion about what was being evaluated, or comments about how well, or poorly, the content of the canvas fit with their design. While these group discussions often gained some momentum, such congregation often spawned new interactions which led to a repartitioning of the group and new individual or small sub-group work.

2) Working in a shared, synchronous space: Nearly all groups arrived at a point in their design where each member was focused on the same discussion or content. Students joined the same canvas in order to better participate with the group (Fig. 8). This behavior was especially prevalent during the brainstorming phase or when the content of the designs required explanation or discussion. Documentation of others' ideas through notations and reorganization or restructuring dominated the activities during these times of shared focus. Students found that this level of collaboration was beneficial in quickly soliciting ideas and evaluating content.

When members of the group were inspired to work separately, their creations often referred to, drew upon, or derived from the work of the group. "[Being] able to jump into any cell and give everyone feedback", as one student put it, illustrates how independent work augmented the efforts and goals of the group and how each student contributed to the work of others.

3) Synchronizing ideas between sub-groups: Sub-groups eventually needed to integrate their ideas and content into final group designs. This lead to a need to bring together work done separately into a unified design. This required that the work in each cell be reviewed and considered in turn to verify that their sketched designs adhered to where their thinking had evolved.

Groups used various means to integrate and evaluate separate work. Calico’s grid view, which provides a bird's eye view of all available canvases, was instrumental in the review process of many groups. While in the grid view, groups discussed each design in turn, entering the cell if changes were to be made. Some groups utilized Calico’s palette to bring work together. By creating scraps out of sketches and placing them on the palette, students were able to pull the scrap from the canvas to the palette and back to any canvas, copying the scrap as often as necessary. While integrating work, one group found that other members had strong opinions on, and suggestions for, the design of others. In response, they decided to adjust their composition, rotating students among the subgroups, and proceeded to continue work on the designs.

Using Calico to bring separate work together seemed, in most respects, to be second nature to the students. As one might lay out pieces of paper in front of oneself, the students naturally used the grid view to review designs at a bird's eye view.

4) Taking inspiration from group members: When designing, inspiration may come from many sources, including the comments and actions of other designers. Working in a studio setting within a group may then afford students a greater opportunity to find inspiration.

During design sessions, all groups engaged in deep discussions over their task and designs, helping to guide their decisions. Students, however, went further. For example, we observed students peeking on the canvases of other group members, even while still working on their own task. Students would switch to the grid view to see where work was being done and jump into a canvas that looked interesting. In one case, a subgroup even began evaluating and discussing alternatives to a design that was still being created in a another subgroup. Interestingly, the discussion of the onlookers about the content was entirely different from the creator's intended use. The creators were preoccupied with their own efforts and unaware of the onlooker’s discussion. Thus, there was no...
attempt by the creators to explain their design, affording the onlookers the beneficial opportunity to explore a different direction. We also observed some teams looking in on the efforts of other groups, in effect checking up on their progress.

5) Democratizing participation: Making content accessible in Calico encouraged students to contribute and interact with the group. Drawing on a single canvas shared among group members allowed, for instance, the layout of an interface to be viewed by students as it was created and discussed. This expanded the avenues of participation, encouraging students to contribute in a variety of ways, such as by sketching, contributing an idea for reorganization, pointing out a potential problem, or writing an anonymous note to suggest an alternative approach. This self-regulated participation occurred even when group members were working separately. Students questioned about the ease of contributing to the group stated that they “did not feel like they were invading anyone’s space” and that “it was great to be able to jump to another cell and give input there if you did not feel comfortable where you were.” These sentiments support the observation that each student was able to freely and repeatedly exert his or her influence when contributing to the group design. The abundant opportunities for expression increased overall participation within the group, a phenomenon found in other tools that allow for synchronous group work [23].

6) Continuity between and beyond classes: In both design projects, students used Calico’s persistent space to carry their design materials between and outside classes. Given that the spatial arrangement of content plays an important role in the thinking process [13], the organization of canvases by the grid helped teams in returning to their work in subsequent classes with minimal context loss. Students also reported that they accessed their team’s content from home to prepare their class presentations, final documentation, and to organize group activities, such as assigning roles and exchanging email addresses.

The persistence of the grid also enabled the instructor to reconfigure groups for the final design studio. In the final session, teams were broken up so that each had one grid with a user interface design, and a second with the software architecture. The students then had to create a final design that merged both the software UI and architecture into a cohesive design. Such as task would have normally required a large overhead for students to bring copies of all their materials or to exchange electronic documents. In the case of the grid, students simply loaded two grids and seamlessly began the exercise without additional effort from the instructor or the students themselves.

V. DISCUSSION

Overall, Calico substantially improved the educational value provided to the students by the design studio approach. First and foremost, the instructor has taught this class for several years in a row, and in the early years would present the students with design problems similar to the ones discussed here, only to see student groups sometimes disappear from the classroom to find a space where they could spread out large sheets of paper to work with each other. Bringing Calico into the classroom not only alleviated this problem, but also enabled the instructor to have much more direct access to the intermediate results being produced.

Rather than shuffling through what still was a small number of drawings, compared to the number of sketches being produced with Calico, students would pull up relevant sketches instantly.

A second difference pertains to the details of the designs that are produced. With pen and paper, designs tended to stay less polished and very rough in nature. With Calico, students have the ability to refine the initial rough sketches and explore their designs in much more detail, which is enabled by the tool’s features to flexibly branch, manipulate, and organize their designs. The result is a design studio in which more meaningful designs and design decisions are discussed, since the students engage with the problem and potential solutions in greater depth.

Third, students seemed much more engaged in the discussions, and participation in the design sessions evened out over the group much more so than with pen and paper. With the latter, one or two tended to dominate the discussion and, as keepers of the physical record, put up an implicit boundary to contributions – others could draw on their own paper, but sharing and integrating such work is harder with pen and paper. With Calico, sharing work is ingrained in the tool that the students use, reducing this hurdle. A secondary benefit is preserving sketches between class periods, providing strong continuity of group effort.

In terms of Calico itself, and how it supported the students in sketching, we observe that students were able to explore and carry out their design process using a variety of considerations, including requirements, scenarios, and user interfaces. Students were able to generate a wide range of artifacts, including lists, informal collections of sketches produced through brainstorming, UI mockups, architecture, and other forms of more formal diagrams.

While some students experienced difficulties using scraps and requested features such as color scraps and straight lines, the degree to which students engaged with Calico indicates that the basic affordances that the scraps feature enabled over plain sketching to be beneficial. Students could have instead entirely ignored scraps and used Calico as an electronic pen and paper. Students overwhelming chose to use Calico’s advanced features to interact with sketches, organize content, and create mockups.

Calico’s grid was particularly helpful in supporting the collaborative aspects of the design studio. It enabled students to effortlessly form subgroups, as well as partition and bring their work together in a seamless manner. Students reported appreciating the simplicity of partitioning, sharing, peeking in, and contributing to work among team members. As the studios unfolded, students were able to naturally work in this fashion.
VI. CONCLUSION AND FUTURE WORK

Overall, Calico is a creative tool that supported students in exploring a design task. It enabled students to play with designs, perform group work, and get feedback from one another as well as the instructor. Student discussions were lively and everyone was engaged in one form or another. In comparison to previous versions of the class, students generated many more intermediate artifacts. Lastly, the instructor had an easier time in moving from one class to the next since the servers remained active, and could challenge the students with unique tasks that built on work from previous classes.

In future work, we aim to examine the results and the activity of the class in greater detail. The complete design history for every group is automatically captured on each Calico team server. We plan on examining the logs generated by these records to get greater insight into how students arrived at their final design.

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REFERENCES


