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Sketchy: Drawing Inspiration from the Crowd

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In-person user studies show that designers draw inspiration by looking at their peers' work while sketching. To recreate this behavior in a virtual environment, we developed Sketchy, a web-based drawing application where users sketch in virtual rooms and use the "Peek" functionality to gain ideas from their peers' sketches in real-time. To assess if "Peek" supports individual creativity through finding inspiration, students from a Human-Computer Interaction class sketched user interface design tasks in two studies. Study 1 compares creativity measures with and without Peek between two groups of students, where self-reports reveal Peek increases satisfaction with their final sketch and better supports individual creativity. Study 2 took place in a large classroom, where 90 students, all with Peek enabled, completed different design tasks. Peeking led students to report an intention to change their sketch 18% of the time in Study 1 and 17% of the time in Study 2. Student designers were influenced by sketches that seem closer to completion, contain more details, and are carefully drawn. They were also about three times more likely to clear their canvas and start over if they found a sketch inspirational. Furthermore, sketches created by students with more sketching and design experience influence less experienced student designers. This work explores the directions and benefits of incorporating digital peeking to support individual creativity within a student designer's classroom experience to create more satisfactory final sketches.

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1 INTRODUCTION

Sketching is a primitive form of human expression, a language dating back to cave paintings. It is an approximation of life as an artistic form. It is a way of thinking, where doodles and outlines start a creative process. In design, it is the first essential step in a series of iterations [8] and generally recognized as part of a suite of Creativity Support Tools [22].

User experience design values sketching as part of the process, to act as a dialogue during ideation [8]. However, in a physical environment, the process of sketching and sharing typically do not co-occur, as space and materials constrain it. For example, simultaneous sketching commonly occurs in classrooms where students individually progress through a given task where they rarely have the opportunity to collaborate and share their progress with their peers [2, 28]. Our preliminary observations show users physically peek (i.e. view another person's sketch) during in-person sketching tasks to gain inspiration. Instead of limiting students to only physically peeking sketches from those sitting next to them, we enable digitally peeking at more random sketches within an entire classroom in real-time.

To assess both how this digital "Peek" ability can affect creativity and which features of a "peeked" sketch are inspirational, we run two studies in a university-level user interface design classroom using a custom-developed web-based sketching application called *Sketchy*. In Sketchy, students sketch on a device they have at hand and can freely peek at their peers' in-progress sketches. To enable Peek in a digital environment, Sketchy automatically synchronizes everyone's sketches in real-time. This way, in-the-moment inspiration can come from a student sitting five rows behind, thus translating the physical experience of sharing sketches into a broader digital setting.

Classroom sketching reveals behavior where such peeking is part of the design process, as Loksa [46] reports, "we observed students peeking on the canvases of other group members, even while still working on their own task." But why? Past research has shown inspiration can "fire the soul", playing an essential role in the creative process [27, 51]. Determining how creative or inspired a student may be is a difficult task, given the inherent ambiguity and subjectivity of these concepts. In the following paragraphs, we define our notions of these concepts as they will be used in this work.

We define creativity as mini-c (personal level) creativity, as derived from Beghetto and Kauffman's taxonomy [35]. Mini-c creativity recognizes "that intrapersonal insights and interpretations, which often live only within the person who created them, are still considered creative acts." To evaluate "personal-creativity", Sketchy aligns itself with the Müller-Wienbergen et al. idea of an Individual Creativity Support Tool [48]. This focus on the individual differs from the group creativity support of 6-3-5 Brainwriting [56] and C-Sketch [60], where an individual only contributes to the group's final design. Similar to past studies of individual creativity support tools identified by Seidel et al. [59], our evaluation compares digitally peeking versus a baseline condition of physically peeking at another sketch using the Creativity Support Index (CSI) [10, 13], to measure a tool's ability to support creativity. Our usage of the CSI follows the recommendations of Wang et al. [72] and prior work by Benedetti et al. [5].

In our preliminary in-person sessions, we observe users peeking their peers' in-progress sketches to gain inspiration for their in-progress designs. Past research and our pilot studies show inspiration is too subjective to analyze quantitatively [64]. Asking a third party or a computational model to label inspiration in real-time is difficult to scale; they are equally unable to reveal what a sketcher is thinking. Why did they change something, and what part of a sketch inspired them? Since one cannot ask the sketcher if they were inspired in-the-moment, could a more direct question serve as a proxy?

Sketchy's idea of in-the-moment inspiration aligns with Cropley's [15] idea that inspiration is "hitting on a solution." From this notion, we define "inspiration" as the process of being stimulated to *imitate* an idea from another sketch. Our definition of inspiration alludes to the idea of intended change. Imitation is difficult to precisely quantify and therefore requires the use of a simple proxy—in this case, posing a direct question to users while they were digitally peeking: "Will you change your sketch based on what you see in this sketch?" Subsequently, we quantify the actions users perform when going back to their canvases and relate them to their answers to this question.

Our direct question follows the creative process explained by Oleynick et al. [51], where the "process of being inspired by gives way to the process of being inspired to, which motivates action." Following peeking, a user's subsequent action represents the "actualization" of their inspiration to bring a creative idea to life, as defined by Thrash et al. [67]., in ways such as peeking again, sketching, or erasing parts of their sketch.

Across our two studies, we investigate the nature of creativity and inspiration based on a user's ability to digitally peek at the nearly unlimited number of sketches being drawn concurrently by their peers. We utilize both Sketchy and the Peek feature in classroom sketching tasks to answer several research questions:

- **R1)** Does having the option to digitally peek lead to higher creativity measures and satisfaction with students' own sketches?
- **R2)** When do students peek, what happens when they peek, and how often does peeking inspire them to change their sketch?
- **R3)** What features of a peeked sketch and its creator are most associated with being inspirational?

The answers to these questions explain the Peek feature's pedagogical contributions to the shared real-time classroom experience, how digitally peeking supports individual creativity, and the potential for a personalized version of Peek.

Our studies show a digital form of peeking compared to traditional physical peeking better supports creativity by increasing users' sense of collaboration, freedom of expression, and feeling of satisfaction that the reward is worth the effort of sketching. Peeking itself is sometimes reported to inspire changes in a user's sketch, but inspiration seems to come more reliably from sketches that are closer to completion, more detailed, and carefully created by more experienced sketchers.

Our findings further show that Sketchy supports an individual's creativity by translating the benefits of physical peeking into a digital setting, thus empowering an entire classroom to both generate individual sketches and gather inspiration from other's sketches in real-time. As part of this work, we release the Sketchy web application[1], the data gathered from almost 500 sketches, and the associated labels of whether they inspired a change in the peeker's sketch.

2 BACKGROUND AND RELATED WORK

2.1 Creativity Support Tools

Creativity Support Tools provide digitally-mediated assistance to enhance the creativity of groups or individuals. In Painting with Bob, Benedetti et al. [5] created a digital painting tool to increase creative expression and evaluated results using the Creativity Support Index [10, 13]. Sketch-Sketch Revolution [20] generates tutorials from sketches and workflows of experts to help novice users. Other systems provide specific instructions for users to follow. For example, ShadowDraw [41] dynamically updates a shadow image underlying a user's strokes (similar to tracing a background image), and Iarussi et al. [31] presented a drawing tool that automatically extracts construction lines to help users draw more accurately. In contrast, Sketchy provides a more leisurely approach

[1]The Sketchy web application and data: https://sketchy.cs.brown.edu/

and allows users the agency to look for inspiration until they are satisfied. This is a passive ideation approach rather than active, which would have required proposing specific actions.

Other Creativity Support Tools focus on educating users, rather than providing assistance, through intelligent tutoring systems that provide personalized feedback. For example, SketchTivity [73] aims to improve creativity by allowing instructors to provide real-time feedback on sketches outside the classroom. Building on the idea of real-time feedback, Keshavabhotla et al. [36] developed a system that applies instructor insights and observed pedagogical practices to develop progressive exercises, which use sketch recognition to give real-time feedback. Other tools blur the line between human and AI feedback on sketches, such as the text-based facilitator used by Walsh and Wronksy [70] to increase engagement with a sketching activity.

Our work does not focus on real-time feedback of sketches, but rather on providing students with a shared real-time progression through sketching tasks. This allows students to find examples from their peers that support their creativity in short tasks, e.g. about 4 minutes, and therefore alleviates the need for instructor interaction or a trained complex model to provide this feedback.

2.2 Providing Inspiration in Iterative Design

Inspiration, recently the subject of many studies, is a key contributor in the creation process [12, 32]. How to support inspiration in art is an open question [69]. Past researchers explored real-time feedback mechanisms [49] in an attempt to support creativity in lab settings. Wang et al. [71] developed IdeaExpander, a system that supports group creativity by showing pictorial stimuli based on dynamic conversational content. Sketchy, however, is evaluated in classrooms rather than lab settings. Extending from prior work, Sketchy examines the role of co-inspiration among peers, as opposed to its role solely on the individual.

Another approach to generate inspiration is for designers to search through collections of prior examples. Juxtapoze generates a database of clip-art using the shape of the intended object [6], while Co-3Deator hierarchically focuses on 3D sketching by directly swapping constituent components for work done by peer designers [54]. Goucher et al. text-mined crowdworker's written design solutions to extract inspiration stimuli that were later presented to participants [24]. In a classroom, it would be time-consuming for crowdworkers to pre-generate all possible stimuli, thus the Peek feature automatically provides these stimuli by allowing students to see random sketches from others simultaneously working on the same task.

Researchers have also ran pilot studies and searched repositories to provide sketching examples at different intervals as stimuli for participants. While Kulkarni et al. showed that repeated exposure to sketches improves the creativity of generated ideas, these ideas were only shown at fixed intervals [38]. Siangliulue et al. showed that allowing users to see examples when they want to, or "on-demand", is more effective [61]. The Peek feature builds on Siangliulue's work by enabling the "on-demand" condition in a realistic classroom setting [61]. Peek relies on a group of users to simultaneously sketch and provide their work as possible inspirational stimuli to their peers. A teacher could use Sketchy for any sketching task without running pilot studies or curating online repositories for inspirational stimuli. This real-time experience of co-creating and inspiring allows for the analysis of not only the sketch itself, but also of the creator.

2.3 Collaboration & Creativity: Shared Progression Encourages Learning

Past research efforts have focused on the benefits of a collaborative environment for improving efficiency and quality in artwork but have failed to study supporting inspiration [58]. Lee [40] aimed to increase collaboration and create complex artifacts by investigating the benefits of asynchronous interactions within real-time collaborations. Exploring these ideas in a paid crowdsourced micro-task environment, Gingold et al. [23] looked at averaging crowdsourced drawings to produce high-quality output from low-quality input. Limpaecher et al. [42] created a stroke-correction method to improve strokes in real-time using a crowdsourced drawing database. Finally, Lasecki et al. [39] created a prototyping tool allowing designers to quickly iterate and gather feedback by automating and crowdsourcing elements of their interfaces.

Researchers have studied asynchronous collaborative analysis in non-sketching settings. Goyal et al. developed SAVANT, a collaborative sensemaking web-based tool, which enables implicit sharing and knowledge synthesis through a post-it note interface [26]. Aandolina et al. uses a similar post-it note whiteboard interface for paid crowdworkers in order to gather real-time creative input during early-stage design activities which would improve brainstorming and concept mapping [1]. In another example, Goyal et al. study implicit knowledge sharing in a collaborative analysis tool [25], showing that participants retain more information and perceive the tool as more useful compared to when sharing is disabled. Sketchy compares its digital collaborative feature Peek against a baseline of physical peeking, thus building upon these ideas of knowledge-sharing in the context of an individuated collaborative sketching approach. Ren et al. proposes fostering a collaborative culture and acknowledges the importance of the individual stakeholder group. Similarly, Sketchy focuses on empowering the individual while also enhancing collaboration [55].

Previous studies emphasized enabling multiple people to collaborate on a single project, with the idea that a group of users will create better designs than individual users [60, 76]. In contrast, our studies show how to support an individual's creativity and satisfaction with their final design by allowing them to see their peers' sketches.

2.4 Analysis of 2D Stroke Data

One goal of this work is to understand what features of a sketch someone might find inspirational. While human behaviors such as sketching or design experience play a part, the analysis of a user's strokes while sketching might yield valuable insights. Eitz et al. [19] performed with 56% accuracy the first large-scale sketch explorations, finding that humans can correctly identify the object category of a sketch 73% of the time. Their study analyzes rasterized sketches, whereas we analyze strokes as sequences of XY coordinates. Our analysis of 2D stroke data, we believe, might be more natural and facilitate simpler synthesis applications. Tu et al. [68] previously demonstrated that sketching with pen and finger gestures are similar in many respects, including articulation time, indicative angle difference, axial symmetry, and proportional shape distance.

Tchalenko [66] noted that novices and professional artists are similarly accurate when drawing simple lines, though experts were inclined to divide complex lines into easy-to-draw segments. However, Liu et al. [45] found that it is common to have strokes with similar geometric properties. Also, different semantics relying on low-level geometric properties such as proximity, continuity, and parallelism, may not be accurate. Our analysis focuses on geometric features derived from hundreds of sketches in order to select the most relevant features to be used for intent classification.

3 PRELIMINARY OBSERVATIONS: IN-PERSON SKETCHING

We ran two preliminary in-person sketching sessions to inform the design of the Sketchy application and its features. The goal was to qualitatively observe how people with a range of abilities performed over several tasks when given a choice to inspect others' work.

Participants were recruited via convenience sampling with occupations ranging from designers and software engineers, to product managers and directors. Participants were from the same large company; hence they could know each other. The two sessions consisted of 6 and 3 participants, respectively (40% female), with an average age of 30 years. Participants sat around a table and used a pen and paper to perform the following tasks:

(0) Sketch a low-fidelity mock-up of a sun. (warm-up task)
(1) Sketch a button a user can click.
(2) Sketch a 5-pointed star.
(3) Create a typeface (i.e. font) and write the word "Sketchy" with it.
(4) Perform a low-fidelity redesign of the Sketchy landing page.

Each task lasted around 3 minutes to simulate the experience of creating and exploring ideas. The idea is for participants to share in their sketching experience in real-time under the same constraints. Participants were not asked to view or imitate each other's sketches.

3.1 Peeking for Ideas and Inspiration

We observed every participant in the first session looking at other participants' sketches when their progress stalled. Participants said they were trying to gain insight on how to sketch a challenging aspect of the task when asked to explain this behavior. For example, in Task 1, P2 looked at P4's sketch because they wanted to imitate how P4's design captured the intention that the 3-dimensional button "needed to be pressed." Participants often spent more time looking at sketches that were either more complete or were drawn by someone more experienced (e.g. professional designers). During their design process, participants examined sketches at different stages of completeness, indicating peeking is potentially beneficial. They would often pause and look at their sketch, and then slowly look around the room at others' sketches. This highlights the importance of the shared experience; participants shared their progression and sought ideas from their peers who had progressed further.

Behaviors supporting the importance of prior experience and level of completeness occurred during Task 2 (designing a typeface) when P3 said, "I might have an advantage because my spouse designs typefaces." After that statement, each participant's attention focused on P3's approach and results. At the core, participants sought to gain ideas from others which they could take back to and use to improve their in-progress sketches. This observation led to the creation of the Peek feature within Sketchy, aiming to serve as the digital equivalent to this physical behavior, and avoiding the constraints of physical environments or the number of participants.

3.2 Inspiration Leads to Imitation

Findings from the second session further emphasize the importance of viewing others' sketches in real-time during sketching tasks. Rather than brainstorming abstract concepts, participants looked for ideas they could observe and bring back to their sketches.

Each participant would sketch a specific concept, such as the spacing between letters, and then try to implement another concept. If their process stopped, they would imitate a concept from another participant through peeking. For example, in the middle of Task 2, P1 paused and tapped their pen on the desk, apparently contemplating their next step. P2 then imitated a concept (thicker lines) from P2 to improve their sketch, see Figure 1. When prompted, P1 felt that when viewing other sketches, "the process is more important than the result."

After the task, we wanted to explore what participants were looking for when physically peeking. As P1 explained, "Seeing what effect works gives me inspiration. If I do not see anything, I have to imagine it. Imagining is hard because it is not concrete." P3 described their ideal learning scenario as one in which "a person would be drawing and presenting it at the same time." Such observations informed the design decision in Sketchy to update the Peeked sketch in real-time. Also, the second session found that participants look for unique features in a sketch to find inspiration. P1 stated, "trying to create something too realistic proved difficult." P1 demonstrated they could improve their typeface design by imitating unique features that inspired them from P2 (Figure 1). From

Fig. 1. In session 2 of preliminary study, P1 improves design by imitating a feature they find inspiring from P2's typeface design. (P1: top; P2: bottom right; P3: left)

our observations, we aim for Sketchy to capture and share this *in-the-moment* inspiration through a digital form of peeking which enables a flexible co-learning experience where all users have equitable access to sketching examples generated in real-time.

4 THE SKETCHY APPLICATION

While the application itself is not the core contribution of this paper, we provide implementation details to contextualize and explain the Peek feature.

4.1 Design Considerations

In our preliminary observations, users seek inspiration from their peers to realize their creative ideas through a shared experience. This observation reinforces the idea that users can inspire each other as they progress through their designs. The Peek feature takes a fundamentally different approach to support creativity: (i) Rather than having a group of students collaboratively create one final design, each student creates their own final design. (ii) Each student has control over their work and can freely choose to view others' in-progress sketches for inspiration. This user-first control allows students to work on similar tasks with their peers without relinquishing independent creative control.

We blended in-person observations with traditional design considerations from literature [5, 8, 61] to support student designers from a user interface design course based on the following principles.

Supporting Creativity: The preliminary in-person study shows that participants can quickly become stuck on an idea without knowing how to implement it. Developing and witnessing many ideas in parallel can produce more diverse and higher quality results [18]. Conversely, choosing a design concept too early can result in design fixation [33], which can limit idea generation, even in experts [16]. The "Peek" feature can help reduce design fixation by exposing users to diverse ideas generated by their peers. Peek allows creators to passively share their in-progress work, like Mosaic [37], enabling users to see sketches evolve in real-time. The timing of seeing sketches in the creative process is also essential; seeing sketches earlier tends to be better for creativity [38]. Users are free to Peek at any moment to help kick-start their creative process since previous research has shown that allowing users to see sketches when they want helps to generate better ideas [61].

Building a Collaborative Space: In design education, designers typically share feedback in co-located studio settings [34]. Participants in design critiques often share their creative work with peers, exchange feedback and reflections, evaluate design approaches, interpret the concepts or artifacts, and brainstorm future possibilities [17]. Through the Peek feature, Sketchy aims to scale the number of participants collaborating by moving this experience into an unlimited virtual space. This space streamlines the ideation and the exploration processes by allowing users to peek at their peers' sketches and then return to their drawings. Sketchy enables a consistent viewing experience across devices within this digital space by smoothing strokes and rendering the final output in Scalable Vector Graphics. This virtual collaborative "space" can enable the creation of classes with a dual format of remote and in-person students, by allowing all students to sketch in a single virtual setting.

Individual results: Different users can create different results. Developing a personal style is critical to creative expression [5]. Sketchy, unlike C-sketch and skWiki, does not constrain users to drawing on another user's sketch [60, 76]. In contrast, users in Sketchy create their sketch without others directly changing their work. In Sketchy, users are free to explore their ideas and create different sketches, a key feature for creative expression (Figure 3).

4.2 Implementation

Based on the design considerations above, Sketchy offers a simple toolkit and functions on devices that users typically carry (mobile, tablet, and laptop), thus allowing for built-in real-time inspiration, which provides each user with their own sketching environment within an infinite virtual collaborative space. These features allow users to create low-fidelity designs through drawing on a

Fig. 2. Users can draw, peek, undo, redo, clear, change stroke color, and view voting history of their sketch using Sketchy's interface.

Fig. 3. Study 2 - Task 2. Users "Design a logo for a company that disposes of E-Waste". Sketches are unique but can share similar concepts, from a lighting bolt and recycling symbols to batteries.

web-based canvas (Figure 2) and to view sketches across different devices and screen sizes while retaining a sketch's intended resolution.

4.2.1 Input Methods. Sketchy has three different input methods. First, in **Drag Mode**, users click, hold, and drag with a mouse or touchpad to draw. In **Drag & Keyboard Mode**, users press and hold the d key while Sketchy records all subsequent mouse movements as strokes. This mode lets users draw with greater precision since each hand performs one action, similar to how someone can draw using one-finger on a touchscreen device. Finally, in **Touch Mode**, users drag their finger to draw strokes, similar to finger painting.

4.2.2 Recording User Interactions. Sketchy records all user interactions: strokes, undo, redo, clear, peeking, and user votes, in a central database.

Sketchy's **draw** tool provides six colors for strokes: blue, green, gray, orange, red, and purple. The intention of implementing simple controls is to decrease the learning curve for the less experienced students in a class. Sketchy simulates a realistic sketching experience by rendering strokes resembling those made by a colored pencil. To simulate the imperfections of colored pencils, Sketchy first renders a fixed-width stroke and then creates smaller strokes with randomized opacity and offset from that initial stroke.

Sketchy has buttons for undo, redo, and clear functionality. Users can **undo** and **redo** all of their previous strokes. **Clear** allows a user to erase their canvas, an action which can indicate that a user wants to change their sketch entirely after peeking.

4.2.3 Peek Feature. While working on the same task, the Peek feature enables a user to view, or "peek", their peer's in-progress sketch. A user will see a peeked sketch update in real-time as their peer progresses, simulating a real-world sketching environment. It is common for users to peek unfinished sketches. Peek selects a random sketch with at least one stroke, and will not show the user the same sketch again unless they view all other sketches. This functionality mimics the observed behaviors from the preliminary in-person study.

To exit the Peek view (Figure 4), users choose Yes or No to the question: "Will you change your sketch based on what you see in this sketch?" The user's vote become labels corresponding to the in-progress sketches. From the earlier preliminary observations, we expect that when a student changes their sketch, this is a positive action, based on the intuition that one would want to change their sketch to make it better.

In sum, the Peek functionality enables the real-time generation and viewing of sketching examples. Unlike prior works, Peek allows users to simultaneously develop ideas and co-inspire each other through the shared experience of using the same system under the same time constraints. Furthermore, in a classroom setting peeking allows students to understand their peers' design decisions, sometimes even watching others change their minds and restart a sketch.

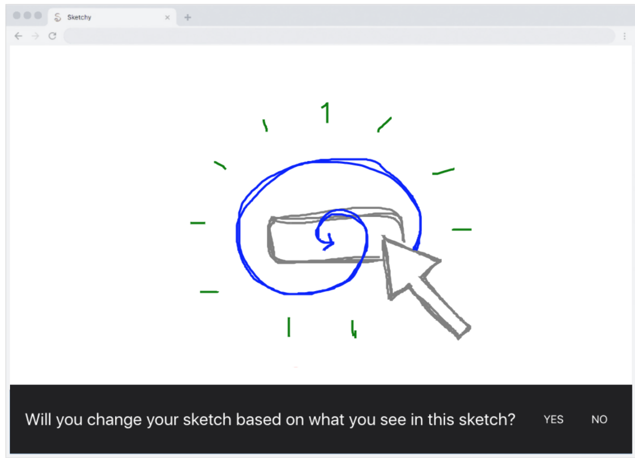

Fig. 4. The interface users see when they Peek. The peeked sketch will update in real-time if new strokes are added or undone. To exit this interface they must answer the above question with either a “Yes” or “No”.

5 STUDY PROCEDURE FOR USER STUDIES

We conducted two studies to answer our research questions. Study 1 seeks to address R1 with a between-subjects study design, while both studies evaluate R2. Study 2 addresses the descriptive question R3 through its larger sample size. Both studies demonstrate how Sketchy and its digital Peek feature can be used in different style classrooms. Study 1 is run in an informal lab setting with multiple round tables, while Study 2 is run in a large classroom (an auditorium in this case). By running these two studies, we can observe the Peek feature in the context of R2 across a diverse set of six sketching tasks versus three.

Students voluntarily participated in both studies (without earning course credit or a grade). They consented to participate in the study and share their data anonymously. Six $9.50 gift cards to a local restaurant were raffled. The prompt for each task was informed by prior pilot studies. Both studies lasted about 20 minutes, and besides the 1 minute warm-up tasks, students were given 4 minutes to complete each task and were never asked to peek. The data from the warm-up tasks was not used for analysis.

When Peek was enabled, students saw a slide showing how to use it. In our pilot testing, we observed students often physically peeking at the screens of others sitting next to them. Hence, when Peek was not enabled, we told students it was okay to look at their neighbor’s screen. In Study 1, we could compare the results of physical versus digital peeking because all students sketch with the same digital drawing tools available in Sketchy. Our local Institutional Review Board approved these procedures.

5.1 Study 1: Creativity Differences with the Peek Feature

Study 1 was conducted during a snack break (as depicted in Figure 5) between two different lab sessions of a university user interface course. It compared creativity measures with and without the Peek feature, using the Creativity Support Index [10, 13], between two groups of undergraduate and graduate students from a user interface class.

Students voluntarily signed up for the lab session of their choice. They had no prior knowledge of Sketchy. The first group of 58 students used a version of Sketchy without the Peek feature. The second group of 41 different students used Sketchy with Peek enabled. A digital form of peeking should theoretically expose students to more sketches than physically peeking at the screens of

Fig. 5. Students sketching in a lounge during Study 1.

students next to them. We removed students from the analysis who did not complete all tasks, including the survey at the end. The analysis consists of 31 and 28 students respectively.

The students were asked to perform one warm-up task to familiarize themselves with the system and then three design tasks:

(0) Draw a tree. (warm-up task)
(1) Draw an icon that represents saving to disk on a computer. No floppy disk icons are allowed.
(2) Draw a logo for a water utility company called Clean Water. The logo must contain the letters "C" and "W".
(3) Draw a gesture that desktop computer users can trace out with their mouse in order to simulate a click, without having to physically click. The main challenge is for the design to be difficult to perform accidentally, while being easy to perform intentionally.

5.2 Study 2: Peek Behavior and Inspiration in a Classroom

We conducted Study 2 at the end of a user interface design class with 115 students who volunteered to stay. From that initial group, 90 students completed all parts of the study, including a pre- and post-survey. All students in this study used Sketchy with the ability to Peek at any time.

Some participants may overlap with Study 1, but the exact number is unknown because the data is anonymous. In this study, students performed four slightly different design tasks, for a change of pace:

(0) Draw an expressive face. (warm-up task)
(1) Draw an icon to represent drinkable water.
(2) Design a logo for a company that disposes of E-Waste. An added constraint was that the logo must have contained the letters "E" and "W".
(3) Draw a pattern for a mouse to trace that will erase whatever is underneath the mouse cursor.

5.3 Study Surveys

First, students consent to the study procedures and answer the following multiple choice questions using Likert scale responses:

(1) What is your level of sketch experience?
(2) What is your level of design experience?
(3) How likely are you to sketch ideas before starting a project?
(4) How effective do you feel viewing other Sketches would be for improving your own sketch?

(5) Which of the following methods do you typically use to gain inspiration for graphic design? The options for this question were "Looking at photographs of real-world objects", "View images of designs on the Internet", "Find a collaborator", "Other", and "None".

During the study, when students digitally peek, they answer a question asking whether the sketch they saw would cause them to alter their own sketch. During our pilot studies, we deliberated about different ways to determine if a user gained value from peeking at a sketch. Simply asking if the sketch provided value or inspiration was ill-defined and not specific enough for participants. Automatic estimates of whether an action came as a result of peeking are also challenging to define computationally. [64, 74]. Eventually, we decided to ask the user whether they intended to change their sketch after they peeked. This operationalization of *inspiration* seemed more manageable for users to judge quickly and serves as a meaningful proxy for *inspiration* as an outcome. So after viewing a sketch, the user is prompted, "Will you change your sketch based on what you see in this sketch?"

We ran a pilot study to assess if participants should answer this question using a binary response (Yes/No) versus a 5-point Likert scale. We found no differences comparing each question type. Hence, we decided to use a simpler binary question for participants to answer when peeking.

After completing each sketching task, students rated how satisfied they were with their final sketch using a 5-point Likert scale. Finally, after completing all tasks, in a the post-survey students completed the Likert scale questions, assessed Sketchy by ranking the components for the Creativity Support Index [10, 13], and answered the following questions:

(1) *Students in Baseline (No Digital Peeking):* How effective was viewing the sketches of people sitting next to you for inspiration?
(2) *Students who only used Peek:* How effective was the Peek feature for finding inspirational sketches?
(3) All students: How effective was viewing a sketch conceptually different from your own for inspiration?
(4) All students: How effective was viewing a sketch conceptually similar to your own for inspiration?

6 RESULTS

In this section we first evaluate the results of Study 1 to answer R1. Then, we present results from the small and large classroom studies, Studies 1 and 2 respectively, to answer RQs 2 and 3. Finally, to ensure a balanced sample, we evaluate the 2D stroke data from Study 2 to answer R3, since Study 2 had four times as many peeks as Study 1.

To investigate these research questions, t-tests were used to compare both the results between conditions, including Likert-scale responses, and the 2D stroke data following the guidance provided by past findings [4, 50, 63]. Unless otherwise specified, data passed both the Shapiro-Wilk test of normality and Levene's test of homogeneity of variances.

Our analysis is conducted per peek because different users are exposed to different stimuli at different times. Students see a new sketch at every peek because sketches are continuously updated. Each action (sketch, undo, redo, or clear) can cause a sketch to change while being peeked. Typically, we would need to aggregate multiple peeks on a sketch if multiple users saw the same version of that sketch at the same time. We conducted an analysis that shows this did not occur.

6.1 Data Overview

Overall, across the two studies, 149 students completed all requirements and performed 447 tasks, sketching over 10,000 strokes, and peeking 3,631 times. Across all studies 61% of students used a mobile device (i.e. a phone or tablet). The next two sub-sections provide answers to possible questions about participation and device usage in both studies.

6.1.1 Peeking Increased Completion Rates of Tasks. Students' data was only used if they completed the entire study. Participation was voluntary, and they could leave at any time. In Study 1, 53% of students who had Peek disabled completed all tasks, compared to 68% of students who had Peek enabled. This result shows that Peek can increase engagement across the same set of tasks. In Study 2 (large classroom) all students had Peek enabled and 78% fully participated. A combination of factors, such as timing, setting, and tasks, could influence this increase in participation.

6.1.2 Controlling for Mobile Devices. The device used (mobile versus non-mobile) did not affect the timing or frequency of peeking, or the number of sketches that inspired a design change per student in either study. Notably, peeking a sketch made on the same type of device did not affect if a sketched inspired a design change. Hence, students can peek sketches made on any device. These results show users can bring their own device when using Sketchy, and the distribution of mobile versus non-mobile devices will not affect the perceived quality of sketches.

	Study 1 (N=28)			**Study 2 (N=90)**			**Total**
Task	*1*	*2*	*3*	*1*	*2*	*3*	
Average Peeks per student	6	10	10	10	8	14	31
Total peeks	166	273	289	923	734	1,246	3,631
Peeks that led to an intention to change sketch	20%	22%	13%	16%	21%	14%	17%
Students who intended at least one sketch change	46%	75%	61%	36%	43%	46%	72%

Table 1. Summary statistics for Peeking in Study 1 (Peek Group) and Study 2 (Large Class). The **Total** column summarizes both studies. Task 0 was a warm-up and therefore is not analyzed. Peeking was frequent across all tasks, and students intended to change their design after peeking 18% of the time in Study 1 and 17% of the time in Study 2. Students peeked more on average per task when there was a lower chance a peek would lead to a design change, indicating students kept searching for an inspirational sketch.

6.2 Digitally Peeking Leads to Creativity

Study 1 was a between-groups study that compared a group of 28 students with the Peek feature enabled to a group of 31 students without it. The students who did not have Peek enabled relied on physically peeking in the social setting of the lounge. Students reported their perceptions from peeking and responded to the Creativity Support Index survey in an end-to-study survey. Creativity measures were higher in the group with Peek enabled, as seen in Figure 6, with the overall CSI score and three individual component differences being statistically significant.

A higher CSI score indicates better creativity support [13]; in Study 1, the overall CSI score is 72.3 for students with Peek enabled, compared to 64.4 for students without it. A one-tailed t-test reveals this 12% increase in CSI scores while using the Peek feature is statistically significant $t(57) = 2.19$, $p = 0.02$, $d = 0.57$. This result shows that the Peek feature adds creative value to Sketchy, especially when compared to similar tools such as AutoDesk SketchBook Express, which received a CSI score of 64 [13].

6.2.1 Comparing the Creativity Support Index Components. The Creativity Support Index consists of six components, each rated on a 5-point Likert scale. The following three components saw a significant increase when Peek was enabled: Collaboration, Effort/Reward Tradeoff, and Expressiveness.

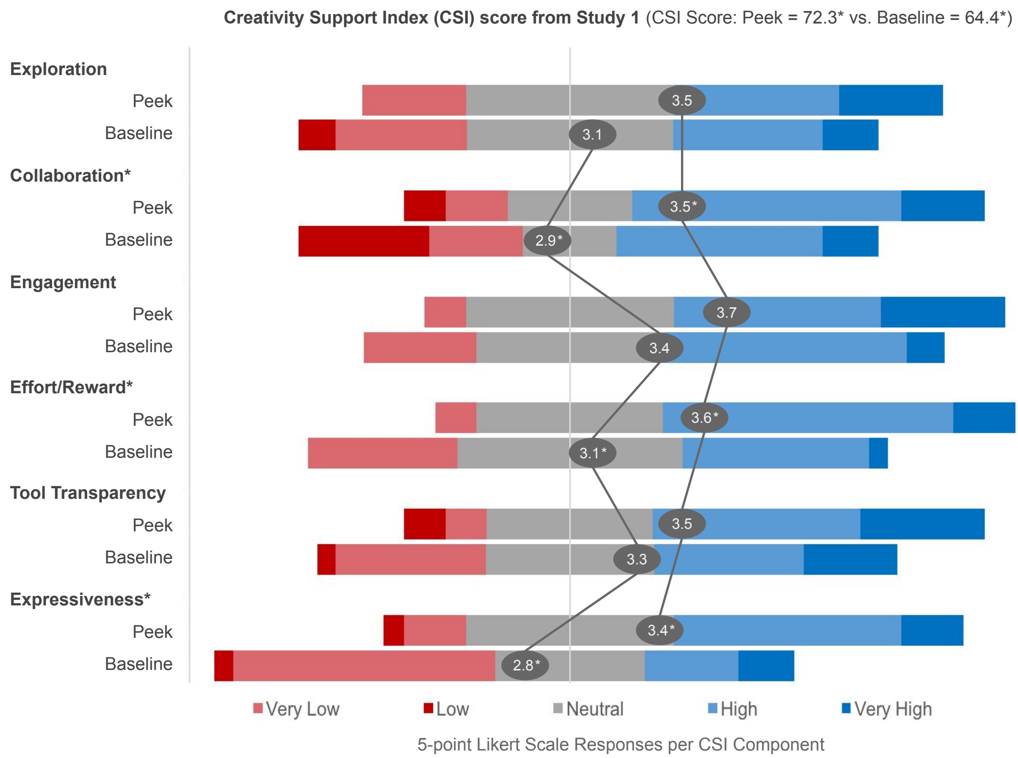

Fig. 6. The CSI score from students who had Peek enabled in Study 1 was 12% higher than the baseline ($p = 0.02$). Each of the average CSI component scores and their distributions were higher than the baseline. Circles contain the mean per component – an asterisk (*) indicates a significant difference between Peek and the baseline. Colors per bar represent the percentage of participants who selected the Likert scale option. These results show that adding the ability to digitally Peek increased creativity.

Collaboration: "I was able to work together with others easily while doing this task." Students with Peek enabled rated the collaboration component 3.52 on average, while students without Peek rated it 2.94. A one-tailed t-test shows this 19% increase in perceived collaboration is statistically significant $t(57) = 1.73$, $p = 0.04$, $d = 0.46$. This result indicates peeking effectively facilitates collaboration and shows Sketchy supports the idea by Ren et al. to create a collaborative culture by adding functionality to empower the individual stakeholder group [55].

Effort/Reward Tradeoff: "What I was able to produce was worth the effort required to produce it." Students with Peek enabled rated the effort/reward tradeoff component 3.71 on average, while students without Peek rated it 3.13. A one-tailed t-test shows this 16% increase in perceived effort/reward is statistically significant $t(57) = 2.42$, $p = 0.01$, $d = 0.63$, indicating that Peek reduces the effort required to create a sketch. Since much of the effort involved in creating a sketch is coming up with an idea, this result indicates that Sketchy can effectively help users find better ways to integrate abstract concepts, see Figure 7.

Expressiveness: "I was able to be very expressive and creative while doing the task." Students with Peek enabled rated the expressiveness component 3.43 on average, while students without Peek rated it 2.84. A one-tailed t-test shows this 21% increase in perceived effort/reward is statistically significant $t(57) = 2.22$, $p = 0.02$, $d = 0.58$, indicating that Peek, by freely exposing students to a wider variety of ideas, allows them to find and express their own concepts better than physically peeking. This result supports the idea that the user should feel as much freedom for creative expression as possible [5].

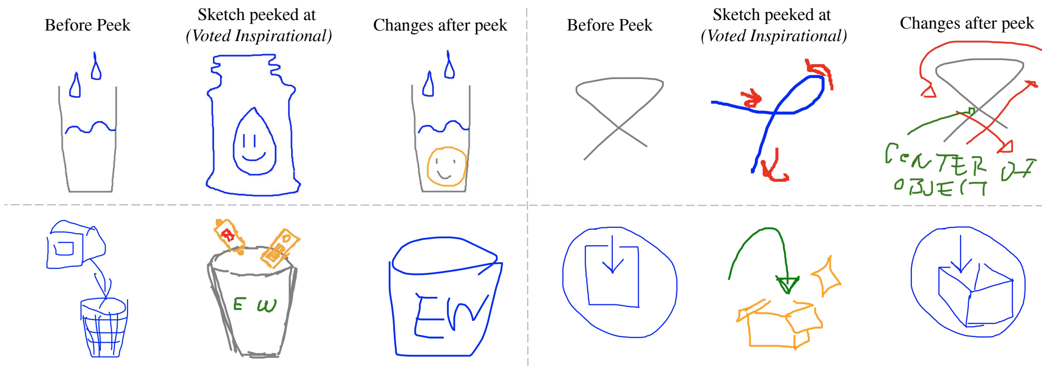

Fig. 7. Examples of students imitating a concept from a peeked sketch they voted as inspirational. The top left sketch (Study 2, Task 1) imitates the smiley droplet. The top right sketch (Study 1, Task 3) imitates using red lines with arrows to indicate the cursor direction. The bottom left sketch (Study 1, Task 2) imitates the placement and inclusion of "EW." Lastly, the bottom right sketch (Study 1, Task 1) imitates the box's 3D dimensional shape.

6.2.2 Physical vs. Digital Peeking. Sketchy's Peek feature seeks to digitally mimic the act of physically peeking over one's shoulder. Students who had Peek enabled were asked "How effective was the Peek feature for finding inspirational sketches?" whereas students who did not use Peek were asked "How effective was viewing the sketches of people sitting next to you for inspiration?" Students from Study 1 found digitally peeking to be 40% more effective than physically looking at their neighbor's sketch for finding inspiration. A two-tailed t-test shows this increase was statistically significant, $t(57) = -4.3$, $p < 0.01$, $d = 1.13$. This shows digitally peeking within a classroom setting can expose students to more ideas in a shorter amount of time than relying on finding ideas from the people sitting next to them.

After each task, students using the Peek feature were asked two separate 5-point Likert scale questions about their experience seeing conceptually similar and different sketches. Generally, students wanted to see sketches that were conceptually different from their own. In the post-survey, students who had Peek enabled were asked: "How effective was viewing a sketch conceptually different from your own for inspiration?" and "How effective was viewing a sketch conceptually similar to your own for inspiration?" Students from Study 1 believed that viewing a sketch conceptually different from their own was around 15% more inspirational. A paired two-tailed t-test shows this difference was statistically significant $t(27) = 2.01$, $p = 0.03$, $d = 0.49$. Also, students from Study 2 believed that viewing a sketch conceptually different from their own was around 11% more inspirational. A paired two-tailed t-test shows this difference was statistically significant $t(89) = 3.42$, $p < 0.01$, $d = 0.38$. These results hold across both small and large settings and across different tasks. A student might want to see a sketch conceptually similar or different during different stages of the creative process. For example, maybe it is more important to view conceptually different sketches during the ideation stage, but conceptually similar sketches during the final stage in order to compare various implementations of ideas.

Students answered how satisfied they were with their final sketch on a 5-point Likert scale after each task. In Study 1, students who had Peek enabled rated their satisfaction an average of

3.60, while students without Peek rated their satisfaction an average of 3.11. A two-tailed t-test shows this 16% increase in the level of satisfaction is statistically significant $t(177) = 2.65, p < 0.01$, $d = 0.46$, indicating the inclusion of Peek led to students feeling more satisfied with their final design for each task. This result shows Peek can increase individual satisfaction by supporting the individual stakeholder, similar to Benedetti et al., instead of supporting the group's final design, such as C-Sketch and skWiki [5, 60, 76].

6.3 Peeking Occurred Often and Inspired Changes

The large classroom study (Study 2) offered additional observations of what happens with peeking behavior in Sketchy at scale. This data combined with Study 1 yields insights across a wider variety of sketching tasks. These quantitative insights focus on how often students peeked, when they peeked, what happened when they peeked, and how often peeking inspired them to alter their own sketch.

In the large scale study, 90 students completed every task and survey, while 28 did so in the smaller setting. There were a total of 2,903 instances of peeking during the classroom study and 728 in the smaller setting. Overall, 58 students (64%) in the large classroom and 27 students (96%) in the smaller setting were inspired to change their sketch at least once. As shown in Figure 7, students took ideas back to their own sketches across a variety of tasks in both studies. Table 1 shows that peeking remained consistent across each task per study, demonstrating that students stayed engaged and continued to use Peek to seek ideas. Peeks in the final task of each study had the lowest chance of inspiring a design change. However, students peeked more frequently during these tasks, indicating a possible relationship between increased peeking and task difficulty.

Table 1 summarizes peeking behavior of students using the Peek feature in Studies 1 and 2. Multiple Peeks were possible during a task. In the classroom study, peeking led to an intentional design change at some point during the task 17% of the time. In the subgroup in Study 1 that used Sketchy with Peek, this happened 18% of the time. The proportion of Peeks leading to a design change was similar between the two groups of users, for both sets of tasks were slightly different in what they asked for but retained the same format.

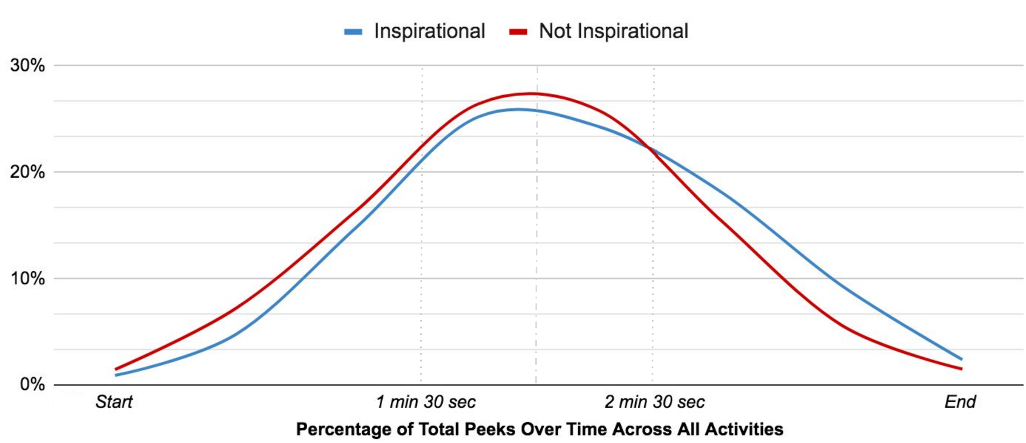

Fig. 8. Distribution of peeks over time across both studies that lead to and did not lead to design changes. Overall, students appear to sketch first and then peek later. While students peeked throughout each task they most commonly peeked during the middle of each task, 68% of peeks occurred between 90–150 seconds after the task began.

Digitally peeking occurred throughout both studies, with 68% of all peeks occurring around the middle of each task, see Figure 8. During the first minute of a task, it was 42% more likely for a sketch to be voted as non-inspirational. This indicates that a sketch might require more details in order for someone to find it inspirational. This cold-start problem begins to dissipate after the 1-minute mark. Across both studies, peeks leading to a reported design change occurred 16 seconds later than peeks that did not. A two-tailed t-test shows this 12% increase was statistically significant $t(3629) = 6.15, p < 0.01, d = 0.26$. These results remain consistent when analyzing Study 1 and Study 2 individually.

In Study 1, peeks resulting in an intended design change occurred 23 seconds later in the task. A two-tailed t-test show this 13% increase was statistically significant $t(726) = 2.93, p < 0.01, d = 0.28$. While in Study 2, peeks resulting in an intended design change occurred 13 seconds later in the task. A two-tailed t-test shows this 11% increase was also statistically significant $t(2901) = 5.84, p < 0.01$, $d = 0.30$. There is a cold start problem for finding sketches since Peek relies on sketches being generated in real-time. Past research relied on prior examples and did not encounter this problem, because they used completed sketches curated through pilot studies or online repositories [38, 61]. This idea is contrary to Sketchy's goal to allow anyone to create and run a sketching task without relying on prior sketches.

Sketchy allows students to see a peeked sketch update in real-time and the freedom to view the sketch for an unlimited amount of time. In both studies, a sketch that was changing while being peeked did not affect whether a student would indicate if they were going to change their design. However, the length of time viewing a sketch while peeking did affect the student's behavior. In Study 1, students viewed sketches for 1.2 seconds longer when they indicated that they would make a design change as a result. A two-tailed t-test shows this 35% increase was statistically significant $t(726) = 3.03, p < 0.01, d = 0.31$. In Study 2, students viewed sketches that they said would change their design for 0.4 seconds longer than a sketch they said would not. A two-tailed t-test shows this 14% increase was statistically significant $t(2901) = 2.32, p = 0.02, d = 0.11$. Results show that time spent viewing can predict whether someone will find a sketch inspirational. This discovery aligns with non-sketching research that focuses on either viewing time and increased interest, memorability, or attention [3, 7, 9]. This result could allow for the automatic rating of sketches as inspirational in real-time, as we discuss later in Section 7.2.

6.4 Users Inspired by the More Experienced

In the pre-survey (see Section 5.3), students self-reported their sketching and design experience on a 5-point Likert scale. These self-reported measures allow us to study whether the experience of peekers and creators influences digital peeking.

Comparing the experience of students who said they would change their sketch versus those who did not helps to answer R2, by understanding why some students found sketches inspirational based on their self-reported experience. On average, students in Study 2 who said they would change their sketch when peeking had 17% less design experience and 10% less sketching experience than those who did not say they would change their sketch. A two-tailed t-test shows this decrease in design experience was statistically significant $t(2901) = -6.14, p < 0.01, d = 0.39$. A two-tailed t-test shows this decrease in sketching experience was statistically significant $t(2901) = -3.47$, $p < 0.01, d = 0.22$. These results may be unsurprising from a pedagogical standpoint, but is a sign that users can gauge their sketching and design confidence. These findings point to the possibility of being able to recommend a sketch to less experienced participants automatically.

Comparing the experience of the student who peeked versus the creator of the sketch can help answer R3, by understanding how differences between their self-reported experience measures might influence proposed sketches changes. In Study 2, students who intended to change their sketch after peeking had 13% less design experience and 6% less sketching experience on average than the creator of the peeked sketch. A paired two-tailed t-test shows this decrease in design experience was statistically significant $t(2902) = -3.62, p < 0.01, d = 0.31$ but the difference in sketching experience was not ($p = 0.14$).

While these findings show a possible beneficial relationship between a less experienced student peeking and a more experienced creator, what about the more experienced students who peeked? In Study 2, students who did not intend to change their sketch after peeking had 4% more design experience and 5% more sketching experience on average than the creator of the sketch they viewed. Separate paired two-tailed t-tests show these increases were statistically significant when comparing design experience $t(2902) = 3.33$, $p < 0.01$, $d = 0.10$; and sketching experience $t(2902) = 3.70$, $p < 0.01$, $d = 0.11$. These results show that sketchers when peeking could benefit from pre-filtering sketches created by their similar or more experienced peers.

While we did not observe the same results in Study 1, future work could control for task, class size, and distribution of sketching/design experience between groups to further study these occurrences. Future work could also develop individuated metrics to understand better how Peek could make recommendations that match a user's in-the-moment needs.

6.5 Peeking Influenced Student's Next Action

A student's next action after digitally peeking can indicate how seeing a possible inspirational sketch can influence their next action. This analysis can help answer R2. After finishing peeking they could perform one of eight possible actions listed in Table 2.

To compare the proportions of students performing one of the eight possible next actions over any of the other actions, we computed two-tailed McNemar's tests with the continuity correction for all proportions. This test is appropriate to assess binary outcomes of repeated measures (in this case, the user actions).

			Additive			Subtractive	
Intended to change design after peeking	**Peek**	**View Stats**	**Change Color**	**Sketch**	**Redo**	**Undo**	**Clear**
Yes	73.8%	7.4%	10.8%	5.3%	0.0%	1.1%	1.6%
No	82.9%	7.2%	5.8%	3.0%	0.0%	0.5%	0.6%
Likelihood	0.9	1.0	1.9	1.7	0.0	2.3	2.8

Table 2. Likelihood to perform a specific action after digitally peeking, as observed in Study 1 (Peek Group) and Study 2 (Large Class). McNemar tests show all relationships with reported effect sizes were statistically significant $p < 0.01$. Notably, the largest differences were in actions that undid or cleared previous strokes, indicating students who intended to change their design were more likely to remove strokes from their design than those who did not.

Regardless of whether a student indicated they would change their sketch when peeking, the most common action was to peek again, as shown in Table 2. However, students across both studies who peeked and voted that they intended to change their sketch did not peek again 26% of the time, and students who indicated they would not change their design did not peek again 17% of the time. A McNemar test shows this 53% increase was statistically significant $\chi^2(1) = 2169.12, p < 0.01$.

While other actions were less common than peeking again, the differences in their occurrences show how students are more likely to add or remove content from their sketch. If students added something new immediately after peeking, they would sketch again, change the color of their next

Fig. 9. In-progress peeked sketches from Tasks 1–3 (top-bottom) from Study 2: The "more inspirational" sketches were often voted as inspirational and scored higher on each of the seven features *(box length, path length, stroke entropy, number of points, number of strokes, sum point differences, and sine end angle)* highlighted in Table 3. The "less inspirational" sketches on the right received little to no votes that a student would change their sketching after peeking them. The inspirational sketches feature a variety of colors, well-spaced objects, long smooth strokes, and extra non-overlapping small strokes that add detail and clarity to the concept of the sketch.

stroke, or redo a previous action. After peeking, students who indicated they would change their sketch were 1.7 times more likely to sketch again as their next action and 1.9 times more likely to change the color of their next stroke than those who did not. Separate McNemar tests show these increases were statistically significant for both sketching $\chi^2(1) = 203.58$, $p < 0.01$ and changing the color of the next stroke $\chi^2(1) = 81.63$, $p < 0.01$.

If students removed something from their sketch immediately after peeking, they could undo the last stroke or clear their canvas to start over from nothing. After peeking, students who indicated they would change their sketch were 2.2 times more likely to undo their last stroke and 2.8 times more likely to clear their canvas than those who did not. Separate McNemar tests show these increases were statistically significant for undo $\chi^2(1) = 385.16$, $p < 0.01$; and clear $\chi^2(1) = 377.75$, $p < 0.01$. These subtractive actions show the biggest differences between action following inspirational and non-inspirational peeks.

Students repeatedly peeking could indicate they want to explore different concepts. Streamlining digital peeking would allow users to consume more ideas in a shorter period. With fewer repeated peeks, it might be possible to observe more non-peeking actions. Maybe students would perform more subtractive actions if Sketchy provided more sophisticated options to erase or undo specific strokes. This could allow for the analysis of what makes specific strokes undesirable after choosing to change their design. Alternatively, it might be quicker for someone to directly copy and paste strokes from a peeked sketch instead of attempting to imitate others' ideas.

6.6 Inspirational Sketches Seem More Complete, Detailed, and Carefully Drawn

We analyzed over 2,000 unique variations of sketches containing multiple possible features. We deliberately ignore low-level features derived from deep learning models since we were interested in the eventual interpretability of features. Therefore, we chose general-purpose features of sketches informed by the research literature on stroke recognition and related areas [14, 21, 29, 30, 43, 44, 47, 52, 53, 57, 62, 65, 75].

We compiled a set of 26 (12 global and 14 local) features shown in Table 3. Global features are features of the sketch that involve many strokes, while local features analyze the properties on an individual stroke basis. The final feature set (**bold** typeface in Table 3) were features that were statistically significant (pairwise two-tailed t-tests with $p < \alpha/26 = 0.002$, with Bonferonni correction) and had a noticeable effect (Cohen's $d > 0.2$).

Global Features	Local Features
Aspect ratio	Avg. point angles
Bounding box angle	Avg. point diff
Bounding box area	Avg. point distances
Bounding box length (d = 0.26)	Sum point angles
Convex hull area	**Sum point differences (d = 0.22)**
Path length (d = 0.23)	Sum point distances
Strokes entropy (d = 0.22)	Sum squared point angles
Number strokes (d = 0.27)	Standard deviation point distances
Number fitted strokes	Standard deviation point diff
Number Points (d = 0.23)	Standard deviation point angles
Number fitted points	Cosine initial angle
Number corners	Sine initial angle
	Cosine end angle
	Sine end angle (d = 0.27)

Table 3. A list of features of 2D stroke data of Peeked sketches from Study 2 evaluated if they cause a participant to change their design. The final feature set (**bold**) is determined where Cohen's $d > 0.20$. Global features, describing the image as a whole, feature more prominently than local features that focus on the quality of the stroke.

6.6.1 *What Makes a Peeked Sketch Inspirational?*

Based on the results from Study 2, we analyzed the sketches from peeks made by students who completed all tasks, then compared the sketches that made participants change their sketch versus the ones that did not.

In principle, the selected feature set suggests that global features determine the inspiration gathered from a sketch more than local features; i.e. if it will cause the user to change their current design. The 21% increase in path length of a sketch ($M_{\text{yes}} = 1,251$ px for inspirational sketches vs $M_{\text{no}} = 1,038$ px for non-inspirational sketches), measured as the sum of point-wise distances, and the 25% increase in its bounding box length ($M_{\text{yes}} = 3,268$ px vs $M_{\text{no}} = 2,606$ px), measured as the length of the bounding box diagonal, are indicators of the duration of the entire drawing. Therefore, more complete sketches are more likely to be perceived as more inspirational, since the user has more information to assess possible inspiration. The notion of completeness is also reflected by the number of points and the number of strokes: a 19% increase in the number of points ($M_{\text{yes}} = 1,172$ points vs $M_{\text{no}} = 986$ points) and a 25% increase in the number of strokes ($M_{\text{yes}} = 20.5$ strokes vs $M_{\text{no}} = 16.4$ strokes), the more likely a sketch is considered "complete". The notion of "information" is also signaled by the strokes entropy, computed as the Shannon entropy of a quantized points sequence in bits, as sketches with higher entropy, a 4.4% increase, usually carry more information ($M_{\text{yes}} = 9.5$ bits vs $M_{\text{no}} = 9.1$ bits) and are correlated with more detailed sketches.

Features that indicated the speed of sketching were also found to be important. Specifically, the sum of point-wise differences ($M_{\text{yes}} = 870$ px vs $M_{\text{no}} = 689$ px) indicates a 26% increase in the perceptible variation in the speed sketches were drawn, and the 37% increase in the sine of the end angle ($M_{\text{yes}} = 6.7$ rad vs $M_{\text{no}} = 4.9$ rad) signals acute changes of direction of the writing strokes, especially at the end of a stroke. Both features suggest that inspirational sketches are more carefully drawn than non-inspirational sketches.

In summary, the final set of 7 features derived from the data from Study 2 suggest that inspirational sketches are more complete, comprise more details, and are more carefully drawn than non-inspirational sketches as seen in Figure 9. In fact, these observations are in line with previous work that investigates 2D stroke features and overall sketch quality [19, 36].

The emphasis on global features points to the aesthetics of the image as a whole. It is less about the actual quality of a stroke and more about the entire sketch. This finding is intuitive because humans do not break down strokes into individual components but instead perceive and assess the sketch as a whole.

Finally, we suspect the differences between inspirational and non-inspirational sketches may vary per sketching task. For example, if students are creating wireframes, then it is likely that inspirational sketches would have more corners and straight lines. Conversely, if the students are drawing the intended movement of a gesture, the number of corners and lines might not be that influential. This analysis, however, is left as an opportunity for future work.

7 DISCUSSION

Peek relies on users concurrently generating ideas in real-time in a virtual space. This setting allows for these groups of users to simultaneously provide sketching examples to everyone else while individually working on their designs. We believe our findings show Peek's effectiveness in real-time classroom activities and the potential for a more intelligent digitally peeking experience.

7.1 Sketchy in Real-Time Classroom Activities

Sketchy comprises several attributes making it particularly suited for real-time classroom activities: flexibility, student-to-student learning, and equitable access. As a design consideration informed by the preliminary observations, Peek's real-time nature gives instructors **flexibility** to define new tasks on an ad-hoc basis without additional preparation. No pre-selected inspirational content is necessary, as learning occurs through observing peers. This same flexibility applies to instruction during the task. The instructor can observe the students' progress and intervene by guiding as needed.

Our results reported that students sought conceptually different sketches for inspiration, which is particularly suited for Sketchy, where students have independent canvases. This independence allows students to continuously peek to find different concepts, without worrying that someone else might alter their design. Peeking in this way fosters student-to-student learning in the form of imitation. As we found, less experienced users were more likely to plan changes when observing more experienced users. Loksa et al. [46] similarly reported, "we observed students peeking on the canvases of other group members, even while still working on their own task." Unlike prior work, Sketchy shows that retaining an independent canvas allows students to engage in **student-to-student learning** while making their own design decisions. Our results showed an increase in creativity measures, including the feeling of collaboration (from 2.9 to 3.5 with peeking). This shared progression is part of the educational experience, and as Loksa et al. [46] also noticed, "[...] some teams [look] in on the efforts of other groups, in effect checking up on their progress." Without a single best way to complete the task, creativity has a greater effect on the sketch.

The Sketchy application is accessible to students' attendance and devices, which is vital in a changing educational environment. Its nature as a responsive web application allows for its use in virtual classrooms, in-person classrooms, or a mix of both (a hybrid classroom). Rather than physically peeking, students access that analogous feature as part of the application, offering **equitable access** to this part of the classroom experience. Whether a student is at home or in the classroom, the bring-your-own-device approach is simple to manage, with flexibility for users sketching with their fingers on a touchscreen or with laptop touch-pads. Sketchy's actual use in multiple classes shows that these three attributes– flexibility, student-to-student learning, and equitable access– make Sketchy a practical tool for real-time classroom activities.

7.1.1 Selecting Tasks for Sketchy. In our work and prior pilot studies we observed a few characteristics that lead to a good task to use for Sketchy. The task's goal must be defined broadly enough for there to be multiple reasonable solutions. We found that the most engaging sketching tasks add constraints to otherwise routine prompts. This constraint gives a mental challenge to overcome for any artist, regardless of their prior sketching ability.

Our results report that students sought conceptually different sketches for inspiration, but this can only occur if there is no single best way to complete the task. We observed that constraints increased creativity by requiring students to create more abstract concepts to complete the task.

Because students use their device, it is important to create tasks suited for phones, tablets, and computers. We found that icons, logos, typefaces, and gestures were appropriate for various devices. Sophisticated interaction design tasks were challenging because it was hard to sketch complex interactions with fingers or laptop touch-pads due to their limited precision. Hence, while wireframes were possible, annotating them with interactions was unsatisfying as there was neither space to portray what would happen during an interaction nor the fidelity to annotate it with text.

7.2 A Smarter, More Personalized Peek Feature

Currently, the Peek feature selects sketches at random. However, our results identify seven notable features from 2D stroke data, the timing of peeks, and self-reported measures of design and sketching experience that influence proposed sketch changes—our proxy for inspiration. We also notice that users want to see conceptually different-looking sketches, something we did not anticipate at the beginning of our study. This initial evidence can inform the development of a smarter, more personalized version of the Peek feature that can help answer the call to investigate "personalized inspirations" by Chan et al. [11] and Siangliulue et al. [61].

A personalized Peek feature could use several filters based on our results to pre-select candidate sketches to show by comparing the peeker and the creator at the time of peeking. These personalized and individuated metrics are dependent on directly comparing the sketches and self-reported measures of the peeker and the creator of a candidate sketch. One filter could ensure the self-reported sketching experience of a candidate sketch's creator is equal to or greater than the peeker's.

Alternatively, pre-filtered candidate sketches could have a higher number of strokes, points, or entropy than the peeker's sketch. This would indicate that the candidate sketch's design has progressed further than the peekers. In the future, sketches could be automatically rated based on their conceptual differences to the user's sketch, these concepts could have similar attributes, but perhaps differences in style or geometry. Pre-filtering sketches based on these personalized features could allow Peek to recommend inspirational sketches faster and at a higher rate than at random. If successful, this personalized model would allow users to sketch more and peek less.

We found other results that could lead to a smarter Peek feature relying on non-personalized metrics. We observed how users imitated ideas they repeatedly saw, despite never indicating an intention to imitate a specific sketch they peeked. Although this is not currently captured by the peek feature, this occurrence shows that viewing multiple sketches could be beneficial for inspiration/creativity. To streamline this process, Peek could show multiple sketches at once or allow users to quickly cycle through multiple sketches before returning to their canvas and asking if they imitated any ideas. Also, a smarter Peek could select groups of conceptually similar sketches to show together or in sequence. This will allow users to quickly consume more inspirational ideas in a shorter time to speed up the creative process.

There are additional opportunities for when it might be predictable that a user would benefit from peeking. If creation and sketching examples are co-occurring, could system intervention be useful in this context? Peek could select the sketch through a combination of prior votes from users or by selecting sketches that match the 2D stroke features we highlight in Table 3. Perhaps there is a highly inspirational on-going sketch, and the system may prompt a user to observe this sketch. Or, could the system only show on-going sketches from users which others have generally found inspirational? This idea of a just-in-time inspiration tool where the system intervenes is similar to past work by Siangliulue et al. [61]. In this manner, it is possible for future researchers to build on our results by comparing personalized and non-personalized features to improve sketch recommendations.

8 LIMITATIONS AND ADDITIONAL FUTURE WORK

Sketchy enables us to explore the concept of design inspiration in the context of viewing another person's sketch during co-occurring real-time design tasks. The participants in our studies had exposure to Sketchy for a limited period of around 20 minutes. Despite evidence that creativity measures increased with the Peek feature's introduction, it is not clear if this was due to the novelty of the feature at the time. Sketchy does not necessarily deliver a tangible approach to improving users' creativity over time, as this would require a consideration of what happens when someone repeatedly uses a tool like Sketchy.

One area for practical, creative improvement is to determine which peeked sketches cause design changes. It is exceptionally challenging to automatically quantify if a user copies specific strokes from the peeked sketch. They might not have the skill to recreate a stroke, or they might only imitate part of an idea, such as size, placement, or orientation. This is why our work relies on a proxy question and studying their next action after peeking. In a more direct method, users could copy-paste strokes directly from a peeked sketch. Then we could study how users integrate and iterate these “copied” strokes through a task. Future analysis could also measure the proportion of strokes or points users directly copy from other sketches.

9 CONCLUSION

In introducing Sketchy's digital Peek functionality to group design settings, we found that collaboration, facilitated by the Peek feature, is key to increasing user's overall creativity and satisfaction with their final sketch. In our preliminary in-person sketching sessions, users exhibited in-person peeking behavior, but some even identified physically peeking as key to how they found inspiring ideas. This collaborative behavior transferred to the digital classroom.

Users generally found sketches inspirational when they were more detailed, complete, carefully drawn, or drawn by someone more experienced. Users drawing with the Peek feature enabled displayed statistically significant increases in the overall CSI score and three of its components: Collaboration, Expressiveness, and Effort/Reward Tradeoff. These results demonstrate that Peek better supports individual creativity and fulfills its potential to increase collaboration by translating a physical behavior into the digital realm.

While collaborative peeking behavior seems key to generating inspiration while sketching within classrooms, it need not remain constrained by the physical boundaries of a class. With Sketchy, we hope to move such collaboration into a virtual space, allowing users to peek at potentially infinitely many other in-progress sketches from other users. Over time, the Peek feature could show sketches better targeting the characteristics that each user finds personally inspiring. Additional data could define when in a task to show certain types of sketches to maximize creative impact. Whether Sketchy will help students to sketch better in the long run remains to be seen. However, students' positive reactions suggest that digitally Peeking helped increase creativity and facilitate collaboration through in-the-moment inspiration.

Sketchy's Peek feature could be used for more than just sketching tasks; it could prove useful, for example, to mathematicians who use shared whiteboards to individually prove theorems, or to schoolchildren who wish to practice their hand-writing. There is a vast amount of co-learning opportunities available across a variety of disciplines that could each benefit from a digital form of peeking.

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