# InStitches: Augmenting Sewing Patterns with Personalized Material-Efficient Practice


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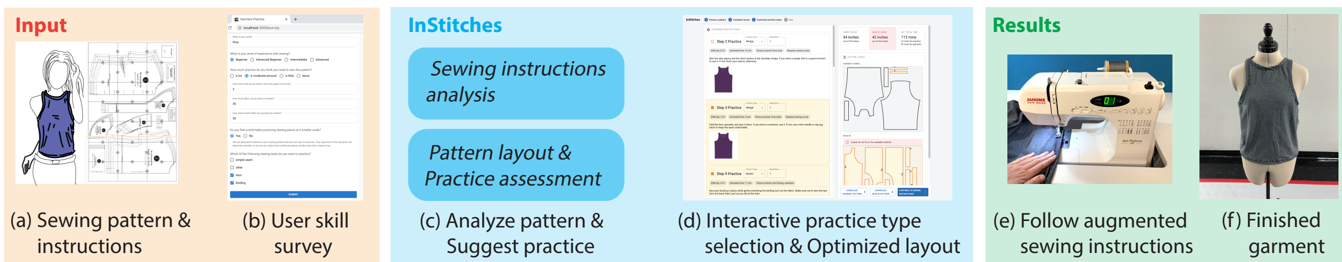


**Figure 1: InStitches augments existing sewing patterns with targeted practice tasks that are efficient in terms of time and materials. Starting with an (a) input sewing pattern and instructions and a (b) user skill survey, it automatically (c) suggests practice steps and (d) provides a layout for creating accompanying practice pieces for tasks that the user is likely to find difficult. The user then (e) follows these interwoven practice and main pattern sewing steps to produce a (f) finished garment.**


## ABSTRACT

There is a rapidly growing group of people learning to sew online. Without hands-on instruction, these learners are often left to discover the challenges and pitfalls of sewing through trial and error, which can be a frustrating and wasteful process. We present InStitches, a software tool that augments existing sewing patterns with targeted practice tasks to guide users through the skills needed to complete their chosen project. InStitches analyzes the difficulty of sewing instructions relative to a user's reported expertise in order to determine where practice will be helpful and then solves for a new pattern layout that incorporates additional practice steps while optimizing for efficient use of available materials. Our user evaluation indicates that InStitches can successfully identify challenging sewing tasks and augment existing sewing patterns with practice tasks that users find helpful, showing promise as a tool for helping those new to the craft.




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## CCS CONCEPTS

• **Human-centered computing → Interactive systems and tools.**

## KEYWORDS

Deliberate practice, Personalized tutorials, Sewing

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## 1 INTRODUCTION

Sewing has a history that long predates most modern technology [24]. For most of this history, practitioners learned the craft through direct apprenticeship, with experts guiding beginners through basic skills. But the Internet has created new opportunities to learn sewing more independently, and online tutorials now bring skills to a large and diverse group of new participants [25]. Sewing is difficult to master, and those who explore it without a guide are left to discover many of its challenges through trial and error. This can be expensive, as each mistake comes at a material cost that can become a limiting factor.

In other domains in which the consequences of individual mistakes can be high—for example, competitive sports, or musical performance—a common mitigating strategy is engagement in *deliberate practice*, which focuses on performing tasks designed to improve the learner's skills in lower-stakes settings. For example, in sports athletes will repeatedly perform drills for specific techniques; while in music, performers will practice scales or repeatedly play the most challenging segments from a longer piece of music. The impact of deliberate practice can be remarkable [22], which is why it may seem surprising that this type of practice is quite uncommon in sewing. But the effectiveness of practice depends on being able to identify useful low-cost practice tasks that target the abilities and objectives of individual learners. In sewing, this can be a tall order; learners usually do not generally know which tasks will be difficult, and even when they do, it can be unclear what form low-cost practice should take. Practice, after all, still requires fabric. As a result, practice is uncommon in sewing and often amounts to multiple unsuccessful attempts at a project.

Our work focuses on understanding the challenges that make practice in sewing so rare and building a tool to help mitigate those challenges in existing workflows. To accomplish this, we present *InStitches*, a system that augments existing sewing patterns with targeted and material-efficient practice tasks that are tailored to the objectives and expertise of individual users. The design of InStitches is driven by three key goals:

- **Integration with existing workflows:** Sewing is rich with tradition and established workflows. A system that is incompatible with these workflows is unlikely to have the same impact as one that complements them. With this in mind, InStitches is designed to work by augmenting existing sewing patterns and instructions.
- **Personalization:** For many learners, a key barrier to incorporating practice in sewing is not being able to identify when practice is necessary in the first place. Most new learners discover that a stitching task is difficult only when they fail to perform it. To be useful, our system needs to identify which tasks will be difficult before those tasks are performed. This requires incorporating knowledge of both the user's skill level and the relative difficulty of different tasks.
- **Efficient material use:** A significant deterrent for practice in sewing is material use. Practice has a material cost, as one still needs fabric to practice on. Without careful planning, this cost can come to outweigh material saved by avoiding mistakes, so to benefit users, we need to ensure that the cost of practice remains low.

The first of these goals aims to minimize barriers to adoption, while the second two highlight aspects of our problem that are particularly well-suited for integration with a computational tool. In the case of personalization, computation offers a way to relate sewing patterns and user skill assessments to information harvested from texts on sewing. In the case of material efficiency, it lets us frame pattern layout as a 2D optimization problem, and by solving for layouts that minimize overall material cost, we can preferentially generate patterns that re-purpose previously wasted fabric to create dedicated practice pieces.

InStitches first identifies steps in a provided sewing pattern that are likely to be difficult for a user. It then optimizes for a new pattern layout and instructions that incorporate practice steps. Users are able to choose among practice tasks generated using three different strategies, each offering different material trade-offs. Our user evaluation indicates that InStitches is able to identify challenging sewing tasks and augment existing sewing patterns with practice tasks that users find helpful. This helps makers explore the craft of sewing in the context of a project of their choice.

## 2 RELATED WORK

While this paper is the first to focus on deliberate practice in sewing, our work draws inspiration from closely related efforts on a variety of adjacent topics.

### 2.1 Deliberate practice

The deliberative practice framework, which argues that targeted practice is essential to skill development, has been applied and evaluated across a wide variety of tasks such as music performance [37], chess [7], writing [22], and software engineering [18, 49]. There are, however, debates about how much practice is needed to achieve a goal and what that practice should look like in different domains [7, 37]. According to Kellogg & Whiteford [22], deliberate practice requires well-designed practice tasks, feedback, repetition, effort, and intrinsic motivation. In domains such as computer science education, guided practice has shown to be widely effective [12] with tools developed to support practicing specific problems, such as Big-O analysis of algorithms [53]. Recent work by Fanfarelli et al. [13] has applied this deliberative practice framework to explore how digital badges could be used to encourage people to practice a wide range of professional skills. In this paper, we also focus on designing a tool to promote practice but in the domain of garment sewing. We incorporate practice steps directly into a process people are already motivated to complete. We consider not only the user's skill level and time but also incorporate an additional element: practicing efficiently in terms of material usage, which is a consideration that arises in many types of physical making tasks.

### 2.2 Learning and Tutorial Systems

Prior work has investigated several strategies for incorporating practice and learning into existing tasks and designing effective tutorials. WaitChatter incorporated vocabulary exercises into a chat app to promote second language learning within the context of an everyday task [6]. Similarly, ALOE replaced English words with words in other languages on existing webpages to help users learn new vocabulary while browsing websites [55]. MixT explored different combinations of text instructions and video demonstrations and supported the creation of multimedia step-by-step tutorials [8]. Several tools have also been developed to support specific domains of tutorials, such as makeup application [54] and physical assembly [9]. There have also been several AR-guided interfaces for authoring and playing back tutorials, including ProcessAR [10] and TutorialLens [23]. While these tools utilize video in their interfaces, InStitches focuses on text instructions, which are common for the application of sewing garments. While there have been several tools developed for guiding users through creating e-textiles, such as [32], little support exists for working with existing sewing patterns. By incorporating domain-specific knowledge about sewing difficulty, InStitches is able to guide users through the challenges specific to sewing.

## 2.3 Physical Making Support Tools

Recently, several tools have been developed to support physical making, such as through using AR to assist assembly [57], sensing to provide feedback on tool usage [16], and projection to help users sculpt an object based on a 3D model [47]. Some tools actively change the path of a tool to correct users' errors, e.g., improving precision in drawing diagrams [59] or correcting the path of tools for 2D cutting [48] and 3D sculpting [60]. Like these prior tools, InStitches helps guide users through a creative process. However, it does this through personalizing the recommended practice steps based on a user's skill level. Additional work focuses on creating short tutorials of physical making tasks [9] or generating assembly instructions automatically [1, 19]. Our work, in contrast, takes existing sewing instructions and adds certain steps for practice.

## 2.4 Textile design tools

Within the HCI community, there has been longstanding interest in textiles as an application space. Recently, researchers developed several design tools for machine knitting to create soft objects and garments [20, 21, 35, 40, 41]. Tools for weaving have been introduced that help weavers understand complex Jacquard patterns [43], combine hand-weaving techniques with computational design [2], and create woven fabrics and circuits together [15]. Tools have also been developed to help quilters create the design of the quilt top [17, 26–28] as well as sew layers of fabric together [30, 31].

Sewing 3D objects, such as garments, typically requires both drafting 2D sewing patterns and constructing the corresponding 3D forms. Several approaches for supporting edits to a design across 2D sewing patterns and 3D forms have been developed for sewing stuffed animals [38] and garments [4, 5, 56]. Some tools help designers navigate specific properties of working with fabric for garments, such as fabric pattern alignment across seams [58] and the addition of folds and pleats as 3D design elements [29].

In our work, we focus on helping users improve their sewing skills by identifying the steps that are challenging to construct in 3D. Most similar to our work, Berthouzoz et al. [5] introduced a method for working with existing home sewing patterns, inferring how the garment should be sewn together based on the geometry of the pattern pieces and generating the corresponding 3D model. However, while this prior work focused on the geometry of the pattern pieces, we instead focus on the text instructions and guide users through the sewing process step-by-step.

# 3 SEWING BACKGROUND

Garment sewing patterns provide the geometric layout and instructions for cutting and assembling clothing. While some advanced garment creators draft their own custom patterns, many people turn to store-bought or downloadable sewing patterns, which typically range in price from $2 to $30 USD. These sewing patterns typically comprise three elements: **pattern pieces**: a set of panels to be cut and sewn together, **cutting layout**: a suggested layout diagram for placing these panels on the fabrics, and **sewing instructions**: written instructions for assembling the panels (see Figure 2).

**Pattern pieces:** The *pattern pieces* delineate the geometric design of each element of the garment. These panels are drafted flat, and some structural elements, such as pleats and gathers are denoted using symbols, such as notches and ticks. Pattern pieces for multiple garment sizes are nested on the page, and the maker typically selects the pieces for a single size to construct their garment.

**Cutting layout:** The *cutting layout* suggests the placement and orientation of the pattern pieces on the fabric. It contains orientation information because fabrics have varying levels of stretch in the warp and weft directions. Following the layout diagram allows for efficient material use and avoids improper orientation that can lead to poor fit and alignment between pieces.

**Sewing instructions:** The *sewing instructions* provide the order for assembling the garment. Each step in the sewing instructions references certain pattern pieces and provides information about how to combine them. These instructions sometimes provide illustrations to explain the construction.

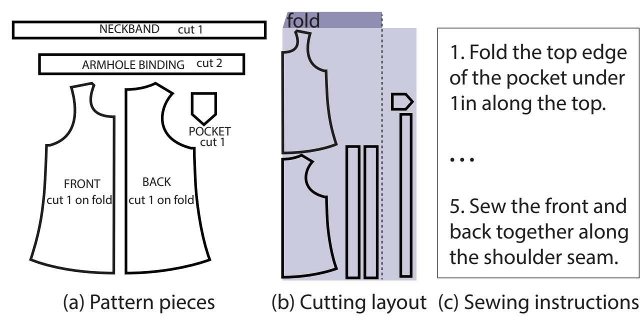



**Figure 2: A sewing pattern comprises three parts: (a) pattern pieces, (b) cutting layout, and (c) sewing instructions.**

Together, these elements—the pattern pieces, cutting layout, and sewing instructions—provide all of the information one needs to complete a garment. However, without the accompanying skills required for a particular pattern, executing the design often leads to costly mistakes. This is where deliberate practice can offer substantial benefits. An important hypothesis of our work is that one barrier to realizing these benefits is the lack of clear strategies or instruction for incorporating practice. Our initial formative study explores what such strategies might look like. Building on our findings, InStitches leverages computation to incorporate these strategies into the pattern, layout, and instructions of existing designs.

# 4 FORMATIVE STUDY: WHAT FORM SHOULD PRACTICE TAKE?

There are many books, tutorials, and videos on sewing and fashion design, but none of the resources we found included instructions or guidelines for deliberate practice (the closest we found was on the use of muslin prototyping, which we describe below). As we discussed in Section 1, part of what makes sewing practice difficult is the lack of a clear way to generate low-cost proxy tasks. To investigate possible solutions to this problem, we conducted a formative study with 9 participants exploring three different

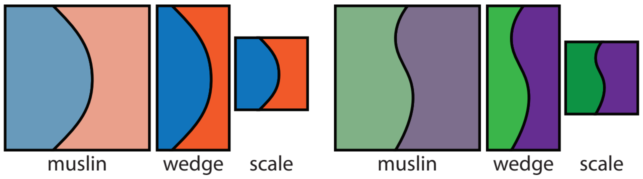



**Figure 3: Each participant sewed 2 curves for 3 practice conditions. The 3 practice conditions include using thinner fabric (muslin), reducing the width of the piece by 50% while maintaining the curvature (wedge), and uniformly scaling the piece 50% in both dimensions (scale).**

approaches to generating reduced-cost practice tasks. Each strategy adjusts material cost by varying a different aspect of the given task:

**Varying scale (Scale):** One way to reduce material use is to scale down the pattern pieces for the step being practiced. This has the advantage of creating pieces that can be assembled in the same order and configuration as their full-size counterparts. However, some properties like curvature are affected by scaling.

**Varying area (Wedge):** Another strategy is to keep a specific seam or pattern edge unchanged while removing fabric from other parts of its containing piece (i.e., cropping a piece around the portion directly involved in a task). This changes the area of fabric used without affecting curvature where stitching occurs. However, this strategy is limited to tasks that only involve pieces of reasonable size.

**Varying material (Muslin):** While our research did not find any examples of established deliberate practice, we did find one prototyping strategy sometimes used to test the fit of garment patterns. The idea is to make a full-scale version of the garment using a less expensive (and typically lighter-weight) material called *muslin*. This strategy requires additional resources and may not reduce material waste initially, but it can help the maker avoid sizing issues in the long run. As such, we include it as an additional approach.

**Study task:** We used each strategy to generate practice tasks for patterns consisting of curves with varying curvature. We chose these patterns for their simplicity, representativeness (such curves are often sub-routines in more complex tasks [33, 34, 50, 51]), and mid-level difficulty [33, 50, 51]. The varying curvature of these patterns is also especially informative for highlighting the difference between our two non-muslin strategies.

**Conditions:** We generated three practice conditions for each task: (1) *scale*: 75% reduction in material, scaled uniformly, (2) *wedge*: 50% reduction in material, with seam curvature remaining the same but reduced piece width, and (3) *muslin*: 100% scale, but with material that was 50% the thickness of the original and half the cost (Fig. 3).

**Participants:** We recruited 9 participants (P1-P9) (8 female, 1 male, mean age: 22) from a local sewing club. They had varying sewing experience levels (3 beginner, 3 advanced beginner, 2 intermediate, 1 advanced), and 5 had prior experience sewing curves.

**Study setup:** We produced all swatches from 6-inch squares made of 100% quilting weight cotton (4oz per sq. in.), except for the lighter-weight material practice condition, which used cheaper muslin fabric (2oz per sq. in.). We pre-cut the fabrics using a laser cutter to create uniform samples for all participants. We chose to pre-cut the fabrics to focus our study strictly on the effect of practice on the sewing step. We also included a 1/4-inch seam allowance along each curve (added after scaling) and instructed participants to sew their swatches at this distance from the fabrics' edges.

**Study procedure:** We gave each participant an overview of the task and sewing machine controls. Participants were assigned to one of two basic domestic sewing machines, each Janome MOD-50's. Each participant practiced sewing two curves of different curvature in each of the practice conditions. First, participants sewed two baseline curves, i.e., one for each of the two curves (Figure 3). After this, participants sewed a practice curve followed by a test curve for each of the two curves in each practice condition, the order of which was randomly assigned. In total, the study took around two hours per participant. We measured the time to complete the task and the accuracy of the sewn sample. After sewing each pair of practice and test curves, participants filled out a questionnaire about how much they enjoyed the practice condition and how helpful they perceived the practice type to be. In our final questionnaire after all pairs were completed, we also included open-ended questions about the participants' attitudes toward practice and sewing.

## 4.1 How long does practice take?

Even if we put aside material costs, practice still comes at a cost of time and effort, and practitioners must weigh this cost against any benefits that said practice brings. This makes time an important consideration for potential practice strategies. We analyzed the results from our formative study to understand how long different practice approaches take to complete. We measured time in two ways: (1) the sewing time, measured from the time of the first stitch to the last one for the seam, and (2) the task time, which is the amount of time the participant took for any preparation to sew, such as pinning or clipping, plus the sewing time. To prepare and sew the swatches, across all conditions, participants took on average 5.07 min (SD = 2.5 min), during which less than half of the time was spent on sewing time 2.08 min (SD = 2.03 min). Because of the large variance in practice times among participants, we examined the ratio of completion times between the baseline swatches and practice swatches for each participant: For the condition that used the lighter-weight material, participants were slightly faster on average (85% of the test time), and several participants noted that this material was easier to work with. For the conditions that used the smaller scale, participants took roughly the same time to sew the full-size and the smaller swatches (1% longer) although they had to sew less material. Decreasing scale increases the curvature of seams, which is generally associated with increased difficulty. For the wedge condition, participants took a bit longer for the practice swatch than for the baseline swatch (14% longer). Although the curvature of the seam is preserved, there is less material holding the fabric in place, which can make the task more challenging. Based on these results, we conclude that all practice options are time consuming, regardless of scale or material, so it is important to select carefully which steps to practice to avoid slowing down the sewing process by adding too many practice steps.

### 4.2 Does practice improve accuracy?

We further analyzed our formative study results to investigate if sewing accuracy improved after practice. To score the accuracy of each sample, we compared the shape of the swatch with the original cutting template. To do this, we photographed each of the swatches on a page with three fiducial markers. We then traced the boundary of the two curved regions in the photograph and the three markers. We averaged the area of the three markers to determine the scale factor for the two curves, and then scaled the participant’s sample accordingly. We then divided the area of the participant’s sewn result with the expected sewing sample area to score the sewing accuracy on a scale from 0 to 1. Regardless of their indicated experience level, participants started at relatively high accuracy scores (M = 0.89, SD = 0.03). 6 of the 9 participants improved from their baseline in at least one of the later tests, and 7 of the 9 participants improved from the first test to the third test for each curve (mean accuracy change = 0.046, SD = 0.037). P3, a participant with intermediate experience, improved the most from their baseline to the final test (0.11). There was no significant difference among the three practice types in improving participants’ accuracy. Throughout the study, participants reported trying different strategies for completing the task, such as pinning and holding the fabrics differently and cutting notches in the curves, some of which were more effective at improving accuracy than others. We observed that participants with higher experience levels took fewer trials to find a good technique for sewing curves. Less experienced participants tended to use several additional trials to try out holding the fabrics in different ways or pinning the fabrics differently, which led to more varied outcomes and less consistent accuracy gains throughout the trials.

### 4.3 What type of practice do people prefer?

When analyzing the questionnaire results, we found that 7 out of 9 participants most enjoyed the cheaper material (muslin) practice, and 6 out of 9 least enjoyed the smaller scale practice. One participant explained that the small scale practice *“was not very useful because it was so small, it impeded the use of the pins the way I wanted them, and it was also unnecessarily difficult to practice on"* (P9). 8 out of 9 participants agreed that the smaller scale practice was most challenging. Several participants (P2, P4, and P5) mentioned in open-ended responses that the lighter-weight material was easier to work with than the typical material. However, P2 actually preferred the smaller scale practice to the lighter weight material practice because the lighter weight one *“felt too basic and all the fun difficulty was gone."* Several participants noted that they sensed that their skills were improving throughout the study, with participants sharing, *“I think my samples generally got better and better as the study went on"* (P9) and *“I felt like I got better each time"* (P5). Participants indicated that a tool that would help them practice in these three ways would encourage them to improve their sewing skills (median = 6 on a 7-point Likert scale).

### 4.4 Formative Study Conclusions

Our formative study indicates that, **when provided with material and instructions, participants find practice enjoyable and practice tends to increase accuracy**. This observation provides the primary motivation for InStitches, which we built with the goal of supplementing existing patterns with practice instructions at minimal added material costs. Other observations from our formative study contributed to more specific aspects of the design of InStitches:

- Different types of practice can be effective in improving accuracy, even at a smaller scale or with cheaper materials.
- Different users expressed preferences for different types of practice, with muslin being the most popular overall but requiring an additional material budget.
- Practice takes time: nearly 1:1 with each original step in the sewing patterns we tested, which may discourage use if suggested practice is deemed unnecessary.

In particular, we use these additional observations to inform our approach to personalization in InStitches. First, we design InStitches to focus practice suggestions on the sewing tasks a user is most likely to find difficult. For this, we need a way to assess the difficulty of each task relative to a user’s experience (Section 5). Second, we make all practice optional, and the selection of practice types (i.e., scale, wedge, or muslin) user-controllable. To accomplish this, we need a way to incorporate a user’s preferred practice type as a constraint on generated layouts and instructions (Sections 6-7).

## 5 TASKS ASSESSMENT AND SELECTION

Like many crafting processes, sewing a garment consists of steps with varying levels of difficulty. While opinions may vary somewhat on the relative difficulty of specific tasks, most garment makers agree at a coarse level on which tasks require more advanced skills. To quantify this kind of difficulty, we identified three popular books on garment sewing [33, 50, 51] that contain relative difficulty ratings assigned to specific tasks (e.g., creating a particular type of collar or seam finishing) and used these to identify and score common sewing tasks according to their difficulty.

Altogether, we extracted difficulty ratings for 53 unique tasks, with 32 of those appearing in each of the three books, 16 appearing in two [50, 51], and 5 appearing only in [33]. Two of the books used a difficulty scale of 1-3, and the third used a scale of 1-4, with low scores indicating easier tasks in all three scales. To unify these scores, we mapped the two tasks that had a score of 4 in [33] to a score of 3 before taking an average of the scores for each task. We then re-normalized these averages to a range of 0 to 10. The average score across the 53 tasks on this scale was 3.5 out of 10.

While reading through the text instructions for each sewing task, we found that the terminology used to describe the construction process varied widely. We therefore chose to further summarize sewing tasks into larger categories with less ambiguous language. Within each book, the sewing tasks are already divided into 10 thematic chapters, including darts, facings, collars, waistbands, sleeves, pockets, seam neatening, zippers, fasteners, and yokes. 8 of these chapters appeared in all three books, darts appeared only in two books [50, 51], and yokes only appeared in one [33]. We used these chapters to group the sewing tasks into higher level

| Category | Sewing Tasks | Avg. Diff. (SD) |
|---|---|---|
| Zipper | Lapped zipper, Centered zipper, Invisible zipper, Faced fly-front zipper | 7.5 (2.0) |
| Collar | Two-piece shirt collar, Simple collar, Peter pan collar | 5.8 (3.8) |
| Sleeve | Set-in sleeve, Pleated sleeve, Puff sleeve, Sleeve self hem, Sleeve elasticized hem, Bound opening, Faced opening, One-piece cuff, One-piece lapped cuff | 5.6 (1.7) |
| Fasteners | Two-hole button, Four-hole button, Shanked button, Oversized and layered buttons, Buttonholes, Covered buttons, Button placket, Hooks and eyes, Snaps | 3.9 (2.8) |
| Darts | Plain dart, Shaping darts to fit, Contour or double pointed dart | 3.3 (2.9) |
| Pocket | Pocket flap, Lined patch pocket, In-seam pocket, Front hip pocket | 3.1 (1.3) |
| Facing | Construction of a facing, Attaching a neck facing, Attaching an armhole facing, Bias-bound neck edge, Waist with a facing | 3.0 (1.1) |
| Yokes | Yoke on a pattern with a shoulder dart, Yoke on a dartless pattern, Yoke shoulder seams (burrito method), Yoke shoulder seams (production style) | 2.5 (2.9) |
| Waistband | Turning under a waistband, Serger stitching a waistband, Bias binding waistband, Attaching a straight waistband, Tie belt | 1.5 (2.2) |
| Seam neatening | Serged hem, Bias-bound hem, Zigzag hem, Pinked finish hem, Curved hem finish, Double-turn hem, Machined hem | 0 (0) |

**Table 1: Sewing operations and their difficulty scores as reported in three popular sewing books [33, 50, 51]. For all sewing tasks not listed in this table, steps are assigned a difficulty score of 0, assuming it is a simple seam.**

categories and averaged the difficulty of the sewing tasks to create category-level difficulty scores as well. These normalized category scores are shown in Table 5. We found that zippers and collars were among the most challenging tasks, while seam neatening was considered least challenging. For our later analysis, we consider all tasks not included in any category as “simple seams," which have a low difficulty rating in all three sewing books.

## 5.1 Sewing task identification:

To automatically score the difficulty of sewing steps in a pattern, we first identify if a step involves sewing by looking for a verb indicating that pieces are being combined. To do this, we collected all of the verbs used to describe the 53 tasks in the three sewing books and had an experienced garment maker identify those verbs related to joining pieces. These join words were: ‘sew,’ ‘stitch,’ ‘attach,’ ‘serge,’ ‘overlock,’ ‘edgestitch,’ ‘topstitch,’ and ‘understitch.’ After identifying if an instruction step contains a join word, we search for mentions of the 10 category labels (Table 5) within the text. Once we match the instructions to a category, we assign the category’s difficulty score. In steps that match multiple category labels, we use the highest difficulty score for each step. For instructions with no labels, we assign a score of 0.

## 5.2 Evaluation of sewing task identification

To evaluate the performance of our system in identifying the sewing task involved in each step, we created a dataset of 14 sewing patterns from 6 different pattern companies (Free Sewing, Fibre Mood, Hey June, Peppermint, Fabrics-Store, and Sew House Seven). In total we had 270 pattern steps (240 sewing steps and 30 preparation, e.g., cutting, pinning, and marking steps) and 77 pattern pieces. We asked an experienced garment maker to manually label the primary sewing task among the 10 choices listed in Table 5 or mark the step as “other" and explain if none of these choices fit.

We obtained 93% accuracy in predicting which of the 10 sewing tasks was involved in each step. For cases in which we predicted the wrong label, either the task name was mentioned in the step although it was not the primary task (e.g., “sew the side seam from the edge of the waistband" was incorrectly labeled as a waistband step) or it contained an overloaded sewing term (e.g., “with the right side of the fabric facing outwards" was labeled as a “facing" step although a different meaning of the word “facing" was intended). Of the 15 sewing steps that were not assigned any of the 10 task labels, all were manually confirmed to correspond to simple seams, which would have low difficulty scores.

The ability to parse sewing instructions and evaluate the difficulty of individual steps gives us a way to identify where added practice is likely to benefit users most. From this we can derive a more concrete objective for our interactive system: to supplement existing patterns with practice steps based on this assessment. What remains is the design of the system itself, which combines our assessment with user-specified preferences and material constraints to supplement existing patterns with useful practice.

# 6 SYSTEM OVERVIEW

The only mandatory input to InStitches is an existing pattern, which users can provide as a PDF or select from the open-source repository FreeSewing [11]. From this input, our system automatically identifies the most challenging steps and produces a new pattern augmented with practice for those steps. The interactive aspects of InStitches are designed to help personalize outputs according to the preferences and constraints of individual users. To this end, we let users provide additional information about their sewing background to customize our difficulty assessment, as well constraints or preferences for particular types of practice, which we use to optimize our generated patterns. Our system supports generating all three of the practice types we explored in our formative study: scale, wedge, and muslin.

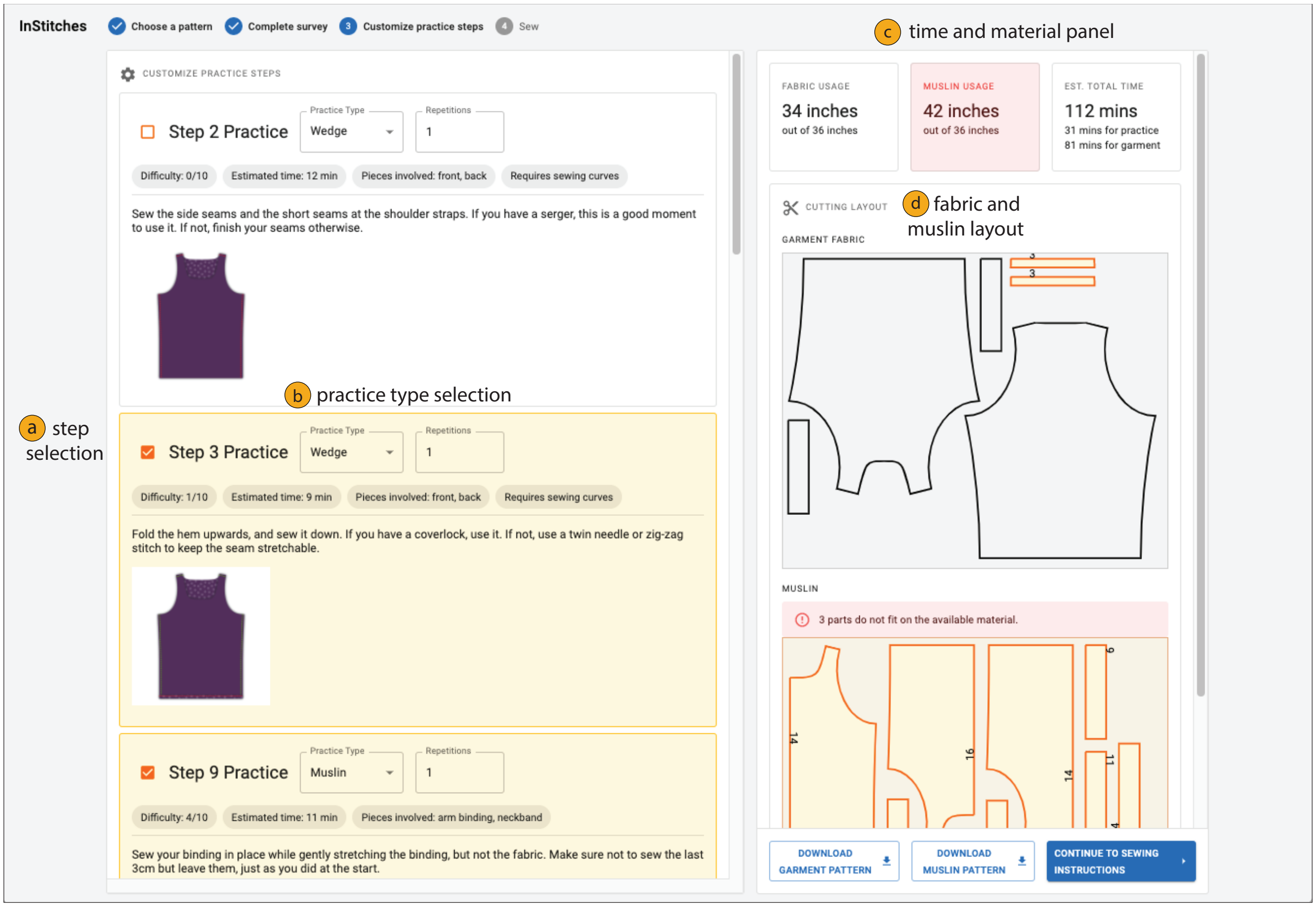



**Figure 4: On the practice preparation page users review the recommended practice steps (a), having the option to add or remove practice steps or repetitions as desired. They can also adjust the type of practice chosen (b), which updates the corresponding material estimates in the time and material panel (c) and the cutting layout (d). The cutting layout makes use of the available leftover material from the garment or additional muslin and lays out the practice pieces. If there is not enough material available, the user receives an alert and can adjust the practice steps chosen or purchase additional supplies.**

## 6.1 Pattern selection

By default, InStitches lets users select a pattern from the open-source sewing pattern repository FreeSewing [11], which allows users to create made-to-measure garments through parameterized patterns. Before starting their practice, users input their measurements to create the custom-sized pattern pieces.

## 6.2 Skills survey

After selecting a garment design, users are asked to fill out a short survey about their prior sewing experience, material availability, and practice preferences. Users first indicate their experience level (i.e., beginner, advanced beginner, intermediate, or advanced), and the system later uses this information to determine if a particular sewing step is above or below the difficulty threshold for the user. Next, the system asks the user how much material they have available, i.e., how much of the main fabric and lightweight muslin fabric they have. Our system uses this information to decide how many steps the user can practice with the available material and what type of practice to recommend. It also asks about the weight of the main fabric. This allows the tool to adjust the difficulty scoring for steps involving particularly light or heavy weight materials, which can be more challenging to sew [33, 50, 51]. Finally, the survey asks the user to indicate their practice preferences, i.e., it gives users the option to indicate specific skills they particularly want to work on (e.g., to make sure they practice any steps involving collars). Steps that involve tasks that are selected here will be recommended to the user as practice steps, independent of how easy or hard they are in comparison to other steps. Users can also indicate if they are comfortable practicing at a smaller scale or if the system should not include this option. We provide this option because the small scale practice received polarized reactions in our formative study.

## 6.3 Practice preparation page

Once the user finishes filling out the survey, they move on to the practice preparation page.

**Practice step selection:** The practice preparation page shows all of the steps that involve sewing in the same order as they occur in the pattern (Figure 4a). It excludes steps not involving sewing, such as marking, clipping corners, and other finishing steps. Based on the user's preferences and skills and our system's analysis of the difficulty of each sewing step, it recommends an initial set of practice steps, which are by default checked for practice in the UI. To provide the user with information about why a step is recommended, the UI shows its difficulty score (0-10), practice type recommendation (e.g., practicing on muslin fabric), an estimate of the time it will take to complete the practice, which pattern pieces are involved, and whether it requires sewing a curve. The user has the option to change these recommendations by selecting or deselecting steps for practice, changing the type of practice for a step, or adding additional practice repetitions (the system recommends at most one by default, but the user can add more) (Figure 4b).

**Total time and material panel:** Every time users update their practice steps, the time and material panel in the UI updates (Figure 4c). In particular, it shows the current fabric and muslin usage and alerts the user if they run out of material and need to adjust their practice, either by selecting different steps or by choosing a practice type that utilizes less material. It also shows the estimated total time for making the garment and distinguishes the time for practice from the time for making the actual garment.

**Cutting layout:** The cutting layout window shows the garment fabric and muslin fabric (Figure 4d) and the laid out pattern pieces and practice pieces for the selected practice steps. Practice pieces are highlighted in orange, while regular garment sewing pieces are outlined in black. Each time the user updates the practice steps, it changes the cutting layouts for the corresponding fabrics.

**Export:** Once the user finishes selecting their practice steps, they can click the 'download garment pattern' and 'download muslin pattern' buttons to print out and cut the practice and garment materials. Once they are ready to sew, they can click on the 'continue to sewing instructions' button, which opens the sewing page.

## 6.4 Sewing page

The Sewing Page guides users through the practice and actual sewing steps. The sewing page includes all of the text and images for each step from the original pattern, including the marking and finishing steps. Each of the practice steps that the user selected on the previous page is inserted immediately ahead of its corresponding sewing step. After sewing each step, the user clicks "next" to move on to the next step, until they have finished their garment.

# 7 IMPLEMENTATION

We next describe how our system extracts the sewing instructions and pattern pieces, creates the cutting layout on the fabric, and generates additional practice pieces.

**Sewing instruction extraction:** FreeSewing patterns come with markdown instructions that are formatted according to their developer community guidelines [11]. We extract the sewing steps from the markdown instructions by going through each text and image block. We isolate the text within the section headers and between paragraph tags and scrape the accompanying images. We treat each block as a separate instruction even if the steps are not numbered. We exclude any videos and links to external websites.

**Pattern piece extraction:** Our goal is to obtain the pattern piece boundaries and labels within each piece to generate practice pieces and create the cutting layouts. To generate a set of custom-sized pattern piece SVGs, our system submits the user's measurements to the FreeSewing API [11], which returns the SVGs with the pattern piece boundaries and labels, such as fold lines and cut instructions. In order to create the smaller scale and wedge practice pieces, we need access to the individual curves in the SVG and the locations of the labels. To extract the boundary curves of the pattern pieces and the labels from the SVGs, we use PyMuPDF [36]. We distinguish pattern pieces from other geometric annotations in the file, such as arrows and tailoring marks, by taking the outermost closed curves on the page (i.e., those curves not contained in any other curves). We identify the number of times a particular piece needs to be cut using a regular expression to find a label with the word "cut" followed by a number. We also identify fold lines by searching for the label "fold" and assigning this label to the nearest curve in the pattern piece. If a fold line is present in the pattern piece, we use it to mirror the pattern piece properly in our fabric cutting layout.

**Fabric cutting layout:** We use a 2D packing tool called Packaide [3] to lay out the the pattern pieces on the fabric and muslin fabric. The layout tool arranges the shapes in a non-overlapping fashion, with a minimum offset distance of 0.6in (1.5cm) to allow for manual cutting. In the examples we tested with 4-24 pattern pieces, it produces a layout in 1-3 seconds, creating a short delay as the user updates their practice choices. To preserve the fabric grain information in the pattern (i.e., the orientation of the fabric's woven threads), we restrict the rotation of the pattern pieces to 0 or 180°. Although many of the input patterns come with instructions to cut pieces "on the fold," our tool simplifies the layout process by automatically mirroring the pattern pieces along the fold line so that all pieces are cut out on a single, unfolded sheet of fabric. While this may add slightly more work for the user to cut out the fabric pieces, it allows the user to better see the remaining material available for practice. We do not mirror the practice pieces intended to be cut on the fold because these pieces are symmetric, so mirroring would duplicate the practice.

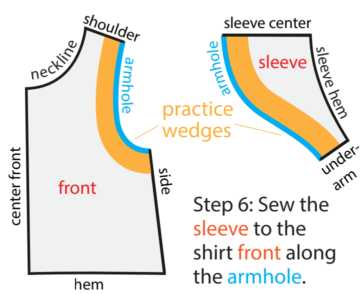
**Material usage estimate:** To estimate material usage, we compute the bounding box around all of the pieces that have been laid out on the fabric and determine the size of the remaining area.

**Time estimate:** We create and update the time estimates for the sewing pattern steps by aggregating data from all of the users who complete a specific pattern. Once a user completes a practice or actual sewing step, we record the time the user took for the step by measuring how long they viewed the step before clicking on "next" and then average it with other users' timing information.

This time includes all of the tasks involved in completing a step, such as preparing the sewing machine, pinning, sewing, etc. If the user indicates they skipped a practice step, we do not include their timing information from this step in our future estimates.

**Scaled practice piece generation:** To produce the smaller scale practice pieces for a particular sewing step, the system scales the pattern pieces involved in this step until the smallest dimension is 3 inches for the smallest piece. This restriction is based on feedback from our formative study about the difficulty of working with pieces smaller than this. For pieces that are originally smaller than 3 inches, such as neckbands or cuffs, we do not allow for smaller scale practice.

**Wedge practice piece generation:** Practice wedges preserve the curvature of the practice step but remove the main area of the fabric to save material. To produce a practice wedge, we must first identify the pattern pieces involved in a particular sewing step and then extract the curve that is being sewn in the step (e.g., sewing the front piece and sleeve along the armhole seam (inset)). To identify which pieces are to be sewn together, we first extract all pattern piece names from the instruction step. Next, for each of the pattern pieces, we extract the curve labels (e.g., "armhole," "hem," and "neckline") from the pattern piece and assign each label to the closest curve. An experienced garment maker manually labeled each of these curves in the pattern pieces for the patterns in our dataset discussed in Section 5.2. We search the text of the sewing step for any mentions of these curve labels. Once we identify the curves involved in each step, we create practice wedges for these curves from the corresponding pattern pieces. To create these wedges, we offset the SVG curve by 3 inches using a piecewise-linear approximation of each curve using svgpathtools [46] and close the resulting wedge polygon. This 3-inch offset comes from our formative study, which indicated it was difficult to work with narrower pieces, which do not have as much fabric to hold onto.




**Practice step recommendation:** The difficulty score displayed to users is the maximum score of any sewing task involved in each step (see Section 5 for more detail). Since the weight of the materials contributes to the difficulty of a sewing task [33, 50, 51], if the user indicates their fabric is heavier or lighter than standard quilting-weight cotton, we increase the difficulty score for each step by 1.0 for light or heavy materials and 2.0 for very light or very heavy materials. To determine which practice steps to include for users based on their skill level, we set difficulty thresholds based on advice from five sewing blogs. These blogs describe which sewing tasks beginner, advanced beginner, intermediate, and advanced garment makers should be able to complete [14, 42, 44, 45] (e.g., intermediate garment makers should be comfortable inserting a set-in sleeve). We examined the difficulty score for each expected task at a particular skill level listed in Table 5 to set the thresholds accordingly. The thresholds we used were: beginner (1), advanced beginner (3), intermediate (5), and advanced (6). Our system then recommends any step for practice with a score above the threshold for the user's skill level. Additionally, if a user specified on the survey page that they were particularly interested in practicing a specific sewing task, any steps involving this task are also recommended, even if the task's difficulty score is below the threshold.

**Practice type recommendation:** To recommend the practice type for each step, our system considers the user's available material and practice preferences. Initially, our tool attempts to lay out practice pieces on the muslin, as this was the most popular and fastest option in our formative study. If there is not enough muslin available, our tool iteratively attempts to switch practice pieces from the muslin to the main fabric by turning them into wedges, starting with the largest pieces. If the pieces still do not fit, it attempts to fit pieces from the remaining steps on the main fabric at a smaller scale and recommends smaller scale practice. If all of the fabric and muslin have been depleted before all of the pattern and practice pieces have been laid out, the UI indicates to the user that some practice pieces will not fit and they must decide whether to skip some practice steps or purchase additional materials.

# 8 NON-PARAMETERIZED PATTERNS

The default input to our system is a parameterized pattern from FreeSewing, but InStitches also allows users to upload sewing pattern PDFs. InStitches parses these PDFs, identifying the text sewing instructions and pattern pieces and labels automatically.

## 8.1 Extracting patterns from PDFs

Our tool accepts PDF patterns with several different page structures, e.g., with different text and image layouts. The main requirements are that the pattern must have sewing instructions ordered top-to-bottom on the page and that each pattern size must be saved on different layers of the PDF file.

**Sewing instruction extraction:** When users upload their own PDF, we extract the text and images from the sewing pattern instructions. To extract the text and images and their location on the page, we use PyMuPDF [36]. In cases in which the text identification fails to extract the steps (often due to special fonts or formatting), we complete an additional pass using Tesseract OCR [52]. We then remove extraneous text from the document, including URLs, hashtags, copyright symbols, and page numbers using regular expressions. We use the location of the text to order the steps and to decide which image goes with each step.

**Pattern piece extraction and labeling:** Similar to how we process parameterized patterns, we extract the pattern pieces and labels using PyMuPDF [36]. However, if the user would like to practice using wedges, they must provide curve-level annotations for the input pattern pieces. Sewing patterns tend to consist of 2-15 pattern pieces with 4-10 curves each. If the user only wants to practice at smaller scale or using muslin, they can simply choose to skip this labeling step.

# 9 USER STUDY

To learn how effective InStitches is at augmenting patterns with practice steps and helping users evaluate the time and material costs of practicing, we conducted a user study with 8 participants in which each participant completed a sewing project with our tool.

**Sewing task:** The study task involved sewing the FreeSewing "Aaron Tank Top" (Figure 1, f). This pattern features several easy sewing steps, such as sewing the shoulder and side seams (diff: 0), and some medium-difficulty steps, such as sewing the neckband and curved armhole bindings (diff: 3.0). In total the pattern has 18 steps, 8 of which involve sewing. The remaining steps involve cutting, marking, or preparing to sew.

**Study procedure:** We gave each participant an overview of the task and sewing machine controls. Participants were assigned to one of two basic home sewing machines (Janome MOD-50's). Each participant filled out the initial survey in InStitches to generate a custom-sized tank top pattern and to indicate their experience level and practice type preferences. They then used the tool to review the suggested practice steps and add or remove practice steps or change the practice type. Each participant was given 1 yard of a lightweight jersey knit stretch fabric (36 x 60in) and 1 yard of muslin (36 x 44in). We assisted users with printing and cutting their patterns and practice pieces. Users then followed the instructions in InStitches to practice and produce their finished top. We instructed participants to complete their work within a two hour period. Participants were then provided with $40 gift cards at the end of the study.

**Participants:** We recruited 8 participants (all women, mean age: 21) from a local textile crafts club. All 8 participants had at least some prior experience using a sewing machine (2 beginner, 2 advanced beginner, 4 intermediate) (Table 2), and 7 of the 8 had sewn garments before. Only two had ever sewn a muslin mock-up, and none of the participants indicated they practice sewing regularly outside of projects. Five of the participants (P2, P3, P5, P6, P7) said they often focus on taking their time sewing. For example, one participant shared, *"I sew recreationally, and I try not to stress myself out when sewing"* (P7). On the other hand, the other three participants (P1, P4, P8) indicated they try to work as quickly as possible. P8 shared, *"I always want to get to the finished product faster!"* 6 of the 8 participants indicated they regularly try to reduce waste and stay aware of their material usage when sewing. Concerned about material costs, P1 shared, *"I usually get a bit more than I need as I know I make mistakes – so I try to be economical, but it's hard"* (P1).

## 9.1 Results

In our study, participants were presented with personalized practice steps, and we explored how participants chose to proceed with sewing their garment based on these suggestions.

**Practice recommendation:** InStitches initially recommended 2 or 3 practice steps for each participant. The time estimates displayed in the UI for completing the task were 97-134 minutes, depending on which practice steps were recommended. In some cases this meant that the expected time exceeded the time of the study slot.

| ID | Exp. | Rec. Practice | Act. Practice | Mistake |
|---|---|---|---|---|
| P1 | Beg. | hem, arm, neck | hem (muslin) | yes |
| P2 | Beg. | hem, arm, neck | neck (scale) | no |
| P3 | Adv. Beg. | hem, arm, neck | none | no |
| P4 | Adv. Beg. | hem, arm, neck | none | yes |
| P5 | Int. | hem, arm, neck | hem (muslin), neck (wedge) | yes |
| P6 | Int. | arm, neck | none | yes |
| P7 | Int. | arm, neck | arm (scale), neck (muslin) | no |
| P8 | Int. | arm, neck | neck (wedge) | no |

**Table 2: InStitches recommended 2 or 3 practice steps for each participant. 7 of the 8 participants skipped at least one practice step, and 4 participants made mistakes on recommended practice steps they chose to skip.**

Additionally, for some participants the pattern pieces for the recommended practice steps could not fit on the available materials. These participants had to select a subset of the steps to practice due to time and material limitations. Participants ended up selecting 1-3 steps for practice in the tool and went on to complete 0-2 practice steps while sewing (Table 2).

**Regretting skipping practice:** We designed InStitches with the principle that users should always be able to opt out of suggested practice steps. 7 out of 8 of our participants made use of this feature by deselecting at least some of the recommended practice (Table 2). Of these, 4 participants ended up making a significant costly error, classified as one that required ripping out an entire seam (P1, P4, P5, P6) (Figure 5). **In every such case, the failed step had been recommended for practice by InStitches, but ignored by the participant. Meanwhile, not a single practiced step resulted in such a failure**. This observation was also reflected in the written feedback of participants. For example, P1 said, *"I should have probably chosen to actually practice binding on muslin at least once, as recommended."* P5 completed an early practice step for the hem, but later opted to skip the practice step for an armhole binding, explaining, *"I thought practicing step 3 (the hem) was very useful [to do] before I worked on it in the actual project. I skipped the practice for step 9 [the armhole] that was recommended because I thought I didn't need it, but that would have been most helpful."*

**InStitches vs. standard patterns:** A majority of our participants (P1, P2, P3, P4, and P5) preferred sewing with InStitches to using standard patterns. The remaining three participants were the most experienced prior to the study, with P7 reporting no preference and P6 and P8 preferring standard patterns. In each of the three cases where a participant did not prefer InStitches, they reported feeling that the added practice was unnecessary given their skill level. However, having made a significant error on a step that InStitches had recommended for practice, P6 (the neutral participant) noted that they believed the system would be valuable for more difficult projects. Among the five participants that preferred InStitches, one participant cited their preference for personalized

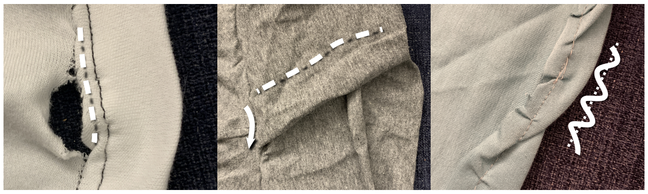



**Figure 5: Several participants made errors after choosing to ignore practice steps suggested by InStitches. P5 skipped the practice for the armhole binding and failed to catch the edge of the shirt with the binding strip, creating a hole. P1 did not practice the armhole binding either and ended up with improper overlap in the underarm area. Instead of sewing a smooth bottom hem, P6 created several unintentional pleats after not practicing this step.**

practice recommendations, sharing, *"The augmented pattern feels far more tailored to me as a sewer than a standard one"* (P2). Another commented on InStitches *"I like how it breaks down the steps for you, how you can go back and forth between steps, and how you can customize the practice types"* (P5). Several participants noted that, even if they felt suggested practice was not needed for this specific project, they thought it could be helpful for other types of projects, particularly those with long and complex processes (P4) and those above a user's current skill level (P1, P2, P3, P6).

**Time and material usage:** The time and material panel and the layout diagrams were the most popular features of InStitches. Participants strongly indicated that the tool helped them be more aware of the materials (median = 7 on a 7-point Likert scale) and time (median = 7) required to practice. Although one participant noted that practicing added time to the process, they shared, *"Working on the specific skills beforehand made sewing the actual garment easier"* (P8). Participants indicated they liked the interwoven practice and actual sewing steps, sharing that it *"made every small step feel like an accomplishment"* (P2) and that it *"almost gamifies sewing a bit"* (P4). P7 said they especially appreciated the feedback about material usage, sharing that this tool fit with their existing sustainable sewing goals: *"I started altering clothes as a personal sustainability initiative so I like not to make too much waste when I sew."*

**Future practice motivation:** Participants indicated that InStitches would motivate them to incorporate practice into their sewing more in the future (median = 6 on a 7-point Likert scale). After skipping the arm binding practice step and making a mistake, resulting in a hole in the shirt, P1 said, *"I want to actually figure out how to sew binding now!"* P1 also indicated they wanted to try this integrated practice approach for knitting. P2 was particularly interested in incorporating practice more in their future sewing projects and suggested adding links to videos or external resources for each step to provide further assistance with challenging tasks, such as the neck binding.

## 10 DISCUSSION

Our work began with the observation that deliberate practice is largely absent from the workflows of most people who sew. This is notable because the comparative high cost of mistakes in sewing would normally make it an especially good candidate for such practice. Our initial research pointed to a few key barriers: most notably, that existing patterns did not contain instructions for practice, and there were no obvious strategies for interested users to design their own low-cost practice tasks. InStitches addresses these barriers by leveraging computation to supplement patterns based on practice strategies that were found to be useful in our formative study. Our study results indicate that the practice suggested by InStitches is useful, but out findings also highlight some current limitations and possible opportunities for future work.

### 10.1 Limitations

Our current implementation of InStitches could be improved in a variety of ways.

**Sewing tasks:** Our formative study and current tool focus on instructions that are composed of several common sewing tasks, e.g., facings, zippers, and collars. To support patterns that include more custom or advanced sewing techniques, such as those used in some formal wear or costume design, we would need to broaden the corpus of sewing references used.

**Dependencies between steps:** InStitches adds targeted practice at the level of individual steps in the sewing pattern instructions. In many cases, practicing these steps in isolation is effective. However, if the original pattern's steps rely on context from previous steps, the practice steps may require some additional preparation. For example, in the 'Aaron tank top' from our user study, there are two separate steps for pinning the neckband into place and for sewing the neckband. In our system, only the sewing step is considered a candidate for practice. In future work, we plan to consider how to identify these dependencies so that we can incorporate relevant preparation.

**Manual curve annotation:** To obtain curve-level information about our sewing pattern pieces, we obtained manual labels for each of the curves in the pattern pieces in our pattern dataset. This curve-level information enables the creation of practice wedges. Without this information, users can only practice at a smaller scale or using muslin. In future work, this curve labeling process could be automated by taking this small set of manual labels and developing a tool to label other pattern pieces with similar geometry.

**Study size and user skill assessment:** One goal of InStitches is to function as a tool to help those learning how to sew. In this regard, we designed the system to adapt to different user skill levels and tested it with participants that had a wide range of sewing experience. However, the limited number of participants in our study makes it difficult to draw confident conclusions about users of a particular skill level. This is further complicated by using self-assessment to measure each user's skill level; our studies showed little evidence that participants who indicated they were more experienced at sewing actually sewed seams more accurately or with fewer mistakes. In the future, studying a larger group of users and evaluating skill based on performance in the study could help with these issues.

### 10.2 Future Directions

Beyond improvements to the current design of InStitches, our work highlights several potential new directions for future research.

**Practice motivation:** Most participants recognized the utility of practice and began their garment with the intention of completing all of the recommended practice steps. However, asking participants to complete their task within two hours created time pressure, and several participants ended up choosing to skip at least one suggested practice step as remaining time decreased. Two participants (P1, P5) explicitly reported regretting this decision. While it is difficult to know for sure if they would have made the same decision under reduced time pressure, or if they would have made the same mistakes had they practiced, their feedback indicates a belief that the skipped practice steps would have been beneficial. Ultimately, the benefits of a system like InStitches depend on users taking its recommendations at least some of the time. This highlights an interesting design dimension to explore in possible future work: how strict should practice suggestions be in a system like InStitches? Our current implementation represents a particularly accommodating point in this design space. Alternatively, one can imagine an interface that hides subsequent steps from the user until suggested practice has been completed. In between these two extremes, one could also imagine designs that display practice suggestions alongside statistics or images showing likely failure modes for the relevant step.

**Evaluation and feedback during use:** Our current system design makes no attempt to evaluate the user's performance at each step, but this could be done manually by asking users to report the success or failure of steps, semi-automatically with an interactive vision-based system, or automatically by augmenting materials with sensors (e.g., conductive thread [39]). The ability to evaluate and adapt to a user's performance in real-time would create opportunities to offer more targeted feedback and encouragement, as well as improve the overall user experience. In the case of a vision-based system, visual feedback could also be offered to highlight potential problems that a beginner might not notice. Integrating evaluation and feedback would also create opportunities to explore gamification of the sewing process and to analyze sewing behavior at larger scales among different users.

**Adapting pattern difficulty**: While our system uses difficulty scores to recommend practice steps, another interesting direction for future work is to use these difficulty scores to make changes to a pattern to simplify it for less experienced makers. Within our dataset of sewing tasks, we found that the difficulty sometimes varied among different construction methods for sewing tasks in the same category. For example, inserting a two-piece shirt-collar has a difficulty score of 10.0, but adding a simple collar only has a score of 5.0. Adjusting individual elements of a sewing pattern can be quite challenging because multiple pieces interact in the finished garment and therefore need to be adapted together. Future work could explore both how to create these design alternatives and how to help users evaluate these design and construction difficulty trade-offs.

**Generalization to other domains:** While the structure of sewing patterns and the language of their accompanying instructions are specific to stitching, our approach of combining domain-specific knowledge of what is challenging and making use of existing structure in making processes can be applied more broadly to other types of fabrication tasks. Other domains, such as woodworking and cooking, that require people to perform tasks of varying difficulty levels in a specified order are good candidates for a similar approach. For example, P1 suggested building a similar tool for knitting. The importance of making users aware of material and time constraints only becomes more critical in domains with higher cost, such as jewelry making and carpentry, and those with longer production times, such as weaving and furniture making.

## 11 CONCLUSION

We began this work by investigating why practice is so uncommon in sewing despite the comparatively high cost of mistakes. Our initial findings led us to believe that much of the barrier to practice could be attributed to a lack of obvious practice strategies. Our formative study supported this hypothesis, suggesting that users could be motivated to practice if provided with appropriate guidance. With these observations in mind, we designed InStitches to augment existing sewing patterns with useful and material-efficient practice steps, and our evaluation suggests that it is effective in this regard. We believe that similar observations can be made in other domains where deliberate practice may have strong potential but strategies for engaging in such practice are difficult for beginners to deduce.

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