An Exploratory Study of Writing and Revising Explicit Programming Strategies

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Abstract Knowledge sharing plays a crucial role throughout all software application development activities. When programmers learn and share through media like Stack overflow, GitHub, Meetups, videos, discussion forums, wikis, and blogs, every developer benefits. However, there is one kind of knowledge that developers share far less often: strategic knowledge for how to approach programming problems (e.g., how to debug server-side Python errors, how to resolve a merge conflict, how to evaluate the stability of an API one is considering for adoption). In this paper, we investigate the feasibility of developers articulating and sharing their strategic knowledge, and the use of these strategies to support other developers in their problem solving. We specifically investigate challenges that developers face in articulating strategies in a form in which other developers can use to increase their productivity. To observe this, we simulated a knowledge sharing platform, asking experts to articulate one of their own strategies and then asked a second set of developers to try to use the strategies and provide feedback on the strategies to authors. During the study, we asked both strategy authors and users to reflect on the challenges they faced. In analyzing the strategies authors created, the use of the strategies, the feedback that users provided to authors, and the difficulties that authors faced addressing this feedback, we found that developers can share strategic knowledge, but authoring strategies requires substantial feedback from diverse audiences to be helpful to programmers with varying prior knowledge. Our results also raise challenging questions about how future...
ture work should support searching and browsing for strategies that support varying prior knowledge.

**Keywords** Programming strategies · Programming tools · Debugging · Social coding

1 Introduction

An essential feature of modern software development is developers sharing knowledge and expertise with other developers through online communities and direct communication. Developers ask and answer questions on Stack Overflow to educate others [26,17], and share knowledge through social media, portals, and online chat [3,31,41]. Open source software development communities rely on knowledge sharing, often supported by openness [39]. Developers share knowledge and expertise on social network platforms such as Yammer, Hacker, and others [48,9,40,41] and in-person by organizing meetups, brownbags, tech talks, and workshops, learning from each other [48,9,40] and asking questions from coworkers within their organization.

However, despite the abundance of knowledge sharing in modern software development, one type of knowledge, *programming strategies*, is rarely shared, and appears only to be gained through experience or through explicit instruction [34]. Prior work defines strategic knowledge in programming as any high-level plan for accomplishing a programming task, describing a series of steps or actions to take to accomplish a goal [22]. Programming strategies reflect knowledge which is procedural in nature, describing not specific concepts, patterns, or styles, but instead reflecting how developers act moment-to-moment when faced with goals and challenges. Experienced developers may choose from a range of strategies for performing their everyday programming tasks. For example, developers have strategies for tasks like diagnosing a performance issue, localizing defects, performing a manual refactoring, and resolving a merge conflict, among countless other software development activities [10,13]. Research on program comprehension suggests that “experts seem to acquire a collection of strategies for performing programming tasks, and these may determine success more than does the programmer’s available knowledge” [15].

Sharing programming strategies could reshape software development and computing education. For example, recent prior work shows that when developers are given explicit programming strategies known to be effective (such as the one shown in Figure 1 which guides developers in following data dependencies to the source of a wrong value) the effectiveness of their work increases by making them more systematic and efficient [22]. Similarly, novices, when given explicit debugging strategies, are far more successful at debugging when they use explicit strategies than when they use their own unsystematic approaches to debugging [21]. Writing effective and explicit programming strategies for the wide range of software development tasks in which developers engage everyday could unlock the accumulated strategic knowledge of experienced developers,
transforming and accelerating software engineering education. It might also even help experts themselves be more efficient.

Yet despite the early promise of explicit programming strategies, it is not clear if developers are broadly capable of sharing their strategic knowledge in meaningful, explicit ways. For example, research on knowledge sharing has long shown that some forms of knowledge are *tacit*, in that they are situated, only effectively learned in context, and challenging to articulate explicitly to others [35]. If strategic knowledge in programming is tacit, it may be that developers know how to solve various problems, but only in the moments in which they enact that knowledge, and not in a form that they can recall and share.

However, it is also possible that strategic knowledge is *not* tacit. Prior work suggests that effective programming is a self-regulated, highly conscious activity [36,25]. This suggests that experienced developers should be able to access their strategies and write them down for sharing. Additionally, software development processes often encode strategic knowledge. For example, methods like test-driven development often provide explicit steps for how to proceed with implementation. This suggests that with some effort, developers can describe the problem solving processes they use and share them with others. Finally, research on human expertise shows that while experts certainly develop their own strategies, they also rely on teachers, who provide strategies, and representations for strategies, that allow them to accelerate their learning [12]. Therefore, it may be that developers can share knowledge by teaching each other; they simply do not tend to teach strategies in popular knowledge sharing media.

In this paper, we investigate these two possibilities of strategic knowledge in programming as either tacit or not. Specifically, we considered:

- **RQ1**: When asked to articulate a programming strategy for particular programming tasks, how do experienced developers’ strategies vary?
- **RQ2**: What challenges do experienced developers report with articulating strategies?
– RQ3: When developers make use of explicit strategies articulated by others, what challenges do they face?
– RQ4: When more experienced developers receive feedback from users of their strategies, what challenges do they face in using this feedback to improve their strategies?

To investigate these questions, we conducted a study with 34 developers, including 19 experienced developers acting as strategy authors and 15 developers acting as strategy users. Our study simulated a knowledge sharing platform in which authors wrote strategies, users used them on programming tasks and provided feedback, and then authors attempted to revise their strategies in response to feedback. Throughout, we gathered the strategies that authors wrote, the feedback that users wrote, and the self-reported experiences of all participants in trying to share strategic knowledge by asking them about the challenges they faced by asking survey questions.

In the rest of this paper, we review related background on knowledge sharing in different domains and in software engineering (Section 2), and then describe our study design in detail (Section 3). We then describe our results, showing that it is possible for experts to share their programming strategies in explicit forms, although they often require substantial feedback to be useful to diverse audiences (Section 4). We then discuss the implications of this work for software engineering (Section 6) and conclude (Section 7).

2 Background

Our work builds on a long history of studies of knowledge sharing and its effects on learning and success. In this section, we review this work and attempt to apply it to the domain of programming.

Knowledge sharing has long been recognized as a fundamental means by which people contribute to work and innovation [19]. There is evidence of achieving more success in educational and industrial environments by sharing strategic knowledge. One study on the relationship of motivational processes to mastery goals found that students who perceived an emphasis on mastery goals used more effective strategies, fostering a way of thinking that is necessary for learning in the classroom [1]. A study examining teaching and learning strategies found that teaching is not only concerned with communicating knowledge but also about developing the skills and strategies for further learning [29]. An evaluation of teaching strategies in the context of a course showed substantial success in affecting study habits and moderate success for students in affecting achievement later in the semester.

At the organizational level, work has considered how to foster effective knowledge sharing between employees. Many organizational managers understand the importance of sharing knowledge between employees, and studies have examined the factors impacting an individuals knowledge sharing attitude in the organizational context, and how to align knowledge sharing with organizational attitudes to motivate employees to change their attitude toward
knowledge sharing [6,28]. Other work has identified factors that significantly influence knowledge sharing between individuals in organizations, including the nature of the knowledge, the motivation to share, opportunities to share, and the culture of the work environment [18]. One review found that interventions may help create social dynamics within the organization that improve knowledge sharing, including interventions targeting the design of information systems, work structures, and human resource policies [8]. These studies illustrate the importance of knowledge sharing to organizations as well as the importance of designing effective information systems and interactions between employees to effectively foster knowledge sharing.

Research on knowledge sharing has identified two forms of knowledge that can be shared: tacit and explicit knowledge. Tacit knowledge is implicit, acquired from experience, and constitutes expertise (e.g., as someone learns to ride a bike, they become more capable of riding a bike, but less capable of explaining how they do it). The opposite of tacit knowledge is explicit knowledge, which is easily transferable through written or natural language. Knowledge is formed from the interaction of tacit and explicit knowledge [2]. Sanchez [43] concludes tacit knowledge is meaningless without explicit knowledge, so both are complementary and essential for knowledge creation.

Studies have found that making tacit knowledge explicit is an important design goal for IT tools [33]. While explicit knowledge can be easily articulated and communicated, tacit knowledge is not easily shared [45], and if it is to be shared, it is costly, slow, and uncertain [16,30]. Polanyi [33] explained that people “can know more than they are able to tell.” There is increasing evidence that tacit knowledge is “the important strategic resource that assists in accomplishing a task” [46]. One crucial benefit that sharing tacit knowledge brings is that eliciting experts’ tacit knowledge helps novices and intermediates to build their knowledge faster and gain more competence. In an organizational context, sharing experts’ tacit knowledge is even more crucial. Experts who leave an organization may cause an organization to lose this knowledge if it not passed to others. This may create a knowledge gap which is costly and time-consuming, or in some cases impossible, to replace [23].

In software engineering, developers share a number types of knowledge in many different ways. Key to software development is the explicit knowledge sharing that occurs through writing and reading documentation in its many forms. Books document a variety of design patterns [14] and architectural styles [38] and how adopting them in a project can help to achieve specific software qualities. Work in software architecture has generated techniques by which developers may choose between architectural and design alternatives to make design decisions [5,11].

There exists a number of approaches, tools, and methodologies that help developers to share knowledge. Agile development methods facilitate developers in sharing knowledge by translating it into explicit knowledge [20], and where developers share tacit knowledge using communication channels in different ways [18]. One frequent form of tacit knowledge sharing includes activities like asking and answering questions on Stack Overflow (SO) to educate
others [17]. Over 92% of developer’s questions about very expert topics are answered in an average of 11 minutes, demonstrating the ease with which some forms of programming knowledge can be shared [27]. Social media [41, 3], portals [44], and online chat [37] are other common forms of crowd-based knowledge sharing. An analysis of 1,730 search results show that blogs covers 87.9% of API methods, featuring tutorials and personal experiences using methods, indicating the breadth of knowledge sharing [32]. Developers share knowledge and expertise through community resources such as GitHub, Yammer, Hacker news, Blogs, podcasts, and social networks such as LinkedIn, Twitter, Facebook, and Coderwall [48, 9, 40, 41].

Developers use programming strategies to solve problems. Programming strategies are one component of programming expertise, which involves a variety of skills for problem solving [15, 24, 4]. Experts gain this knowledge by spending many years working and communicating with others. Studies have examined the process that expert developers use to solve programming problems, listing steps or phases in programming tasks or describing a set of approaches developers choose between. For example, one study enumerated a series of steps that developers go through when making decisions about how to reuse code [42]. Other work has described strategies developer choose between when debugging, such as a backwards or forwards reasoning, code comprehension, input manipulation, offline analysis, and intuition [7]. Work has found that researchers can work to represent programming strategies in an explicit form and teach them to novice developers [34]. Studies have found that having an effective programming strategy can have more of an impact on task success than a programmer’s knowledge [15, 22].

Studies of developers have found that following an effective programming strategy can increase success while reducing task time. A study of slicing strategies for debugging found that those who used slicing while debugging had a better understanding of the problem [13]. Another study found that using slicing enhances localizing the fault in the program while debugging [10]. Teaching novice programmers to follow a strategy to systematically trace execution line-by-line and sketch intermediate values can lead to better performance in predicting the output of short programs [47]. Developers who follow an explicit programming strategy work in a more organized and structured fashion, enabling them to finish their tasks more successfully and in less time [22].

While researchers studying software developers have been able to explicitly identify and teach new strategies to developers, there is no existing evidence that experienced developers can themselves recall and write down their own strategies in a form that others are able to use and follow. Prior work demonstrates that sharing tacit knowledge has many challenges [30], and so sharing programming strategies could be hard as well. In this paper, we examine if expert developers are able to articulate their strategies and, if so, what makes it challenging for them to share their strategic knowledge, and examine how a platform for articulating strategies could help in reducing these difficulties.
3 Methods

In this paper, we investigate several fundamental questions about the nature of writing and sharing explicit programming strategies:

– RQ1: When asked to articulate a programming strategy for particular programming tasks, how do experienced developers’ strategies vary?
– RQ2: What challenges do experienced developers report with articulating strategies?
– RQ3: When developers make use of explicit strategies articulated by others, what challenges do they face?
– RQ4: When more experienced developers receive feedback from users of their strategies, what challenges do they face in using this feedback to improve their strategies?

To answer these questions, we conducted a study in which we simulated a knowledge sharing platform where experienced developers author explicit programming strategies and less experienced developers use these strategies to accelerate their work. Our study consisted of three phases. In the first phase, the first group, which we will call authors, wrote a strategy for a task. In the second phase, the second group, which we will call users, tested the authored strategies and provided feedback and comments. In the third phase, the authors received the users’ comments and feedback and were asked to elaborate about what might make it difficult to address the users’ concerns. In the rest of this section, we describe the tasks (Section 3.1), the notation participants used for articulating strategies (Section 3.2), the participants (Section 3.3), data collection (Section 3.4), and the procedure (Section 3.5).

3.1 Tasks

In selecting tasks, we had several objectives. One approach to investigating strategy authoring would be to simply ask developers to write down a strategy of their own choosing. However, this might make it difficult to identify strategy users who would need this strategy and who had the appropriate expertise, as well as limiting the ability to compare alternative strategies for the same task. Therefore, for this initial study, we chose to select tasks for which we believed authors could write strategies and where we could identify users and contexts in which they could be applied. We sought tasks that were neither too hard, given the limited time available for participants, or too easy, obviating the need for a strategy. We conducted several pilot study sessions with several candidate tasks, ultimately converging on three common front-end web development tasks (Table 1):

– Chrome profiler task: write a strategy to use the Chrome profiler to improve a website’s performance (first row in Table 1).
– Error handling task: write a strategy to verify the robustness of error handling logic in a front-end web application (Second row in Table 1).
Table 1: Authors were each prompted to write a new strategy for one of three programming tasks.

**Chrome profiler task**
Using the Chrome Profiler require an effective strategy to be successful. For example, a naive profiling strategy might be: (1) Load the web application, (2) Start recording performance with the profiler, (3) Look at the flame chart, which visualizes how long various components took to render during the recording, (4) Identify the component taking the most time to render, (5) Optimize the slow component. However, this strategy is not particularly effective. It is not intentional about what data to record, whether that recording is representative of a performance problem, and how to make sure sufficient data is gathered to actually diagnose the problem. It also ignores consideration of which parts of the application you may or may not be able to modify to address the issue.
Your task is to write a better profiling strategy. Your goal is to help other developers learn how to effectively profile any web application. Write your strategy in a way that enables other developers to use your strategy and easily identify the components responsible for slow performance. Consider the following in writing your strategy: What steps should a developer follow to accurately identify slow components? How should they diagnose why those components are slow? What data should they look at? Include enough detail so that a developer experienced in web development and JavaScript, but not in profiling, can be successful.

**Error handling task**
Your task is to write a strategy describing a procedure you use to identify all of the potential errors that might occur in an implemented component and ensure that an appropriate fallback UI message is displayed instead of crashing the component tree. Your strategy should not include steps for implementing error handling logic. It should describe how to identify potential errors and the approach you take to implement error handling for them.
Write your strategy so that other developers can easily identify where they need to add error handling. Consider the following in the strategy you write: What types of errors should the developer consider? What information should the developer gather as they are investigating potential errors and how these are handled? What steps should a developer follow to appropriately handle all possible errors which might occur in the component? Include enough detail so that a developer experienced in web development and JavaScript, but not in writing robust error handling, can be successful.

**CSS debugging task**
Your task is to write a strategy describing how you debug a problem in which the visual style of an element is in some way incorrect. Imagine you are working in code written by other developers with which you are not already completely familiar. What steps will you take to find the cause of the incorrect visual appearance? Your strategy should not include steps to resolve the issue, but we need you to write a strategy on the approach you would take to identify the source of fault.
Write your strategy in a way that enables other developers to use your strategy and easily find out how to fix the visual style problem. Consider the following in the strategy you write: What issues could result in an elements visual style appearing incorrectly? What information should the developer gather as they investigate these issues? What tools or techniques should the developer use, and how can they help gather the necessary information? What steps should the developer follow to accurately diagnose the cause of the issue and apply a fix to resolve the issue? Include enough detail so that a developer with experience in web development and JavaScript, but not in debugging CSS styles, can be successful.
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We found that expertise on these tasks was common enough for experienced developers to be able to write strategies while the approaches for succeeding were variable enough that we could observe a diversity of strategies.

In the second phase, strategy users used an explicit strategy on a programming task and reflected on their experiences using it. Asking developers to use each strategy on authentic tasks of their own would have been ideal. However, finding developers who were encountering these problems in a real context and at a time in which they agreed to participate in the study proved infeasible. Therefore, we instead developed three programming tasks in which strategy users would apply the authors’ strategies. In the Chrome profiler task, we downloaded a JavaScript codebase with performance issues involving moving images and buttons for adding, removing and stopping moving images. Adding an additional moving image caused a significant decrease in the web page’s performance. Users were asked to use an explicit strategy to determine the cause of the performance issue and how to resolve it. In the Error handling task, we developed a JavaScript application containing several error conditions that could occur. Users were asked to use an explicit strategy to identify potential errors which might occur and ensure that each of these error conditions were handled appropriately. In the CSS debugging task, we developed a front-end web application with several visual style defects, including an incorrect header color, incorrect border color, and incorrect background color for buttons. Users were asked to use an explicit strategy to identify the source of the faults and the approach to be taken to implement error handling for them. For each of the tasks, we built a simple web-based IDE with the source code and an execution environment. This minimized the burden on strategy users to prepare an environment for using the strategy.

3.2 Strategy Description Notation

There are many formats in which authors might write their strategies. We considered unstructured natural language, natural language with hierarchical bulleted lists, and other formats. However, to help make strategies as explicit as possible, we choose a more structured representation used in prior work [22] called Roboto. Roboto is mostly natural language but includes some simple control flow constructs such as conditionals and loops to help strategy users be more systematic. We did not require authors to follow it strictly but rather used it as a guideline for how to organize their thoughts and how to communicate more precisely to strategy users.

Figure 2 lists an example Roboto strategy. It describes how to merge two branches of code in GitHub, including fixing any conflicts which may arise. Strategies consist of statements describing what the user should do next. Statements include performing a specified action, gathering information, or making a decision about how to proceed. Statements in Roboto can be one of six forms:
# This Strategy helps you merge 2 branches in GitHub and resolve conflicts

## Required Tools and Environments
- Installing git
- GitHub account
- Ongoing project which is progressing in at least 2 branches
- Git repository that is not associated with GitHub

## Required Knowledge
- Basic git command knowledge
- Knowledge of how to work with terminal and run commands

### STRATEGY GitMerge()

1. Open the terminal, and use `cd` (change directory) command to move to the local git project directory
2. If you are not in the master branch:
   - Run the command `git checkout master` to check out to the master branch
3. If you are in the master branch:
   - To merge the second branch with the master branch run the command `"git merge secondBranch"`, where `secondBranch` is the name of your git second branch
4. Merge the two branches
5. If the merge has a conflict:
   - Set `conflictedFiles` to the project files that have a conflict
   - For each `file` in `conflictedFiles`
     - Fix the conflict
     - Do `fixConflict(file)`
6. Run `GIT STATUS` to see the latest changes
7. Run `GIT ADD`
8. Run `GIT COMMIT -m ""`
9. Run `GIT PUSH`
10. Commit and push the changes

### Strategy fixConflict(conflictedFile)

- Open the `conflictedFile` with your favorite text editor
- Set `line` to a line number that has conflict
- Until the file has no lines of conflict
  - Edit the file following the description
  - Set `line` to the next line number that has conflict

RETURN nothing

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Fig. 2: An example of a Roboto strategy for merging two branches in GitHub.

Action, Definition, Conditional, Loop, Return, or Call [22]. Additional details about each statement can be included through comments, indicated with a hash tag before a statement. Strategies may also include preconditions for using the strategy, listed before the strategy declaration. Preconditions describe required knowledge or familiarity the strategy user should have with technologies, resources, programming languages, tools, environments, or platforms.

### 3.3 Participants

To recruit developers to author strategies, we sought developers with at least three years of experience in front-end web development in any technology stack. We required author participants to be familiar with one of the three tasks. We recruited participants from developers who were alumni of the authors’ institutions. We asked author participants to evaluate themselves on their expertise with each of the tasks to decide if they were qualified to author a strategy. Three invited authors did not consider themselves qualified and withdrew before a task was assigned. Nine author participants withdrew after we assigned the task for a variety of reasons, including insufficient familiarity with front-end web development and insufficient time. Of these participants, several expressed interest in participating as user participants.
To recruit developers to use strategies, we sought developers with a diverse range of programming experience to understand the range of possible difficulties developers with different skills might face in using a strategy. We required user participants to be at least 18 years old and to be familiar with front-end web development, including JavaScript, HTML, and CSS. We recruited user participants from the alumni of authors’ institutions as well as graduate students in computer science and software engineering at both institutions.

We collected demographic data from both authors and users. We asked both about their prior industrial software development and web-based application development expertise, the number of web-based applications and software applications projects they have worked on, and the largest software or web application they have developed. Finally, we asked them to share a brief qualitative description of their programming and work experience background in a few sentences as well as a link to any professional profile they might have (e.g., LinkedIn, GitHub).

Our participants included 19 author participants who authored a strategy (identified as A1-A19) and 15 user participants (identified as U1-U15). Table 2 gives demographic information for each of the 19 authors. Authors ranged in years of experience in software or web application development from 3 to 48 years (median 9 years) and reported having developed between 0 to 1,000 software applications (median 10) and 2 to 40 web-based applications (median 7). Users ranged in programming experience from 6 months to 9 years with a median of 3 years experience.

3.4 Data

To answer our research questions, we collected survey responses in each phase of the study.

In the authoring phase after writing their strategy, authors were asked to complete a survey about the difficulties they faced. We brainstormed difficulties they might face when authoring a strategy and prompted them to reflect on these potential difficulties to help them recall their experiences. Authors rated their level of agreement on a 5 point scale with seven potential difficulties and then briefly described their experiences for each difficulty (Figure 3(d)). Authors were then prompted to share any other difficulties they experienced (Figure 2(f)).

In the testing phase after users finished using each of the two strategies, we asked them to consider five questions about their experiences with the author’s strategy. We asked what made it challenging to work with the strategy and if the challenge was related to a specific line of the strategy, we asked them to specify the related line. Second, users were asked to consider what aspects or features they thought were missing in the strategy. Third, users were asked what additional information or details would make it easier for them to follow the strategy. Fourth, we asked users to consider if the strategy was clear and, if
Table 2: Authors’ reported development experience: number of software application developed (SW), number of web-based applications developed (Web), years of experience in software or web application development (Exp), and employment and web technology experience (Background)

| Author | SW | Web | Exp | Background |
|--------|----|-----|-----|------------|
| A1     | 3  | 7   | 8   | Full stack developer, back-end, ASP.NET, and SQL. |
| A2     | 5  | 2   | 16  | React.js, Vue.js, and other JavaScript frameworks |
| A3     | 14 | 10  | 15.5| Systems architect, UX, full stack developer |
| A4     | 30 | 30  | 20  | GitHub, UML, R, Python, C/C++, Java, HTML/CSS, JavaScript, MSON, XAML, C# |
| A5     | 20 | 12  | 11  | HTML, JavaScript, CSS, PHP, JSP, JSF, C#, Angular |
| A6     | 10 | 5   | 6   | Back-end developer, solution design engineer |
| A7     | 0  | 40  | 23  | Full-stack web developer, SQL Server and C# |
| A8     | 10 | 10  | 5   | Senior software developer |
| A9     | 20 | 20  | 13  | MVC with PHP, JS, HTML, and CSS. |
| A10    | 7  | 4   | 5   | C#, Jquery, ASP.NET, CSS, HTML5, and JavaScript |
| A11    | 10 | 10  | 10  | Full-stack engineer, multiple large-scale systems |
| A12    | 6  | 5   | 8   | Enterprise web applications, SQL in Azure |
| A13    | 30 | 15  | 9   | Full-stack web (Python, PHP, JavaScript), network monitoring (Clojure, JavaScript), mobile (Java for Android), VR (C#, JavaScript), and educational games (Python, JavaScript) |
| A14    | 6  | 3   | 5   | Senior software developer and freelancer |
| A15    | 6  | 6   | 6   | Senior software engineer, full-stack development |
| A16    | 10 | 5   | 5   | Software engineer, open source contributor, freelancer |
| A17    | 50 | 3   | 9   | Data processing and data visualization |
| A18    | 6  | 2   | 3   | HTML, CSS, JavaScript, Python, Java, Angular, Node |
| A19    | 1000 | 15 | 48  | My resume last I checked was about 11 pages or so. I have worked at 13 large companies. |

3.5 Procedure

The study consisted of three phases and was conducted entirely remotely through email and dedicated web pages for each phase.

3.5.1 Phase One: Authoring

After agreeing to participate and selecting one of the three tasks, authors began phase one. Authors first read a brief consent form and a tutorial about
programming strategies and the syntax of Roboto. Participants were shown an example illustrating a strategy for lifting up state in React and given an overview of the Roboto syntax (Figure 3(a)). Participants then stepped through a detailed tutorial of each of the Roboto language constructs (Figure 3(b)), with a strategy example on the right panel highlighting the related statements for each Roboto language construct in turn (Figure 3(d)). Authors were able to freely navigate between the tutorial steps to review. To help authors understand how to write strategies, authors next read several guidelines for authoring strategies (Figure 3(c)). The guidelines asked authors to define the strategy step by step, describe required tools, environments, and knowledge, use comments to elaborate, avoid wasted work, include explicit restarts and rationale, and encourage externalization.

Authors next received a task based on their preferred topic of choice, from one of the tasks described in Table 1. Authors then wrote their strategy in a text editor panel (Figure 3(e)). Immediately to the right of the panel, authors could view a sample Roboto strategy. We believed an example would help in recalling Roboto syntax if they chose to write the strategy in Roboto as well as the structure we encouraged them to follow. We did not apply any syntax checking or text highlighting in the text editor panel as we meant to give the authors flexibility in selecting their preferred way of describing the strategy in Roboto or natural language. Authors then completed the survey on the difficulties they faced and completed the demographic items.

Authors were given one week in which to complete and submit phase one, with a series of reminders and extensions given on days 5, 7, and 12.

3.5.2 Phase Two: Strategy Use

After agreeing to participate, users began phase two. Users first read a brief consent form and an introduction to programming strategies. Users were then given the same detailed tutorial of Roboto language constructs as authors (Figure 3(a,b)). Users were then asked to try out two authored strategies on programming tasks. Users were given a task description (Figure 4(a) depicts the description for the Chrome Profiler task) as well as one of the authors’ strategies (Figure 4(b)). To complete the programming task, users received a link in the task description to an online IDE configured with the code (Figure 4(c)). Users were asked to finish the task using the strategy step by step and to try to perform the actions the strategy asked them to perform in the programming task. After they finished testing the strategy, users were asked to complete the survey items about the challenges they faced in using the strategy (Figure 4(d)). After completing the first task, users then applied a second authors’ strategy on a second task and again completed the survey items on challenges. Finally, users completed the demographic items. Users were given four days in which to complete and submit phase two, with a series of reminders and extensions given on days 3, 4, and 9.

After each user submitted their feedback on the strategy, one of the experimenters read their feedback. If the feedback was unclear, we asked them
Fig. 3: In phase one, authors were given guidelines for writing strategies (a, b, c), asked to write down one of their own strategies (e), and asked to reflect on the challenges they experienced (d, f).

follow-up questions for clarification or to include additional details. We requested the clarification through a shared document with a copy of their responses and the strategy they used, asking the user to clarify marked responses. Multiple rounds of follow-up communication was continued until we completely understand the user responses. User participants who completed the study received a $30 Amazon gift card.
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3.5.3 Phase Three: Revision

In phase 3, we sent the users’ responses about challenges they faced using the strategy to its author. Authors then completed the survey items assessing each response they received. Author participants who completed the study received a $40 Amazon gift card.
4 Results

Our analysis focused on answering four research questions. First, we examined the ways in which developers choose to articulate and make explicit their strategies (RQ1). Second, as developers went about articulating their strategies, we examined the difficulties they faced (RQ2). Third, as other developers made use of these strategies, we examined the challenges that strategy users experienced in making use of these strategies in programming tasks (RQ3). Finally, based on the feedback from strategy users to strategy authors, we investigated the challenges that strategy authors experienced in improving their strategies based on the feedback they received (RQ4). Figure 5 overviews each phase of the study and how the results were generated.

4.1 RQ1: Variation in Authored Strategies

Overall, we found that all 19 strategy authors were able to write down a strategy for their chosen tasks. These strategies varied in length from 4 lines for a strategy for the Chrome Profiler task to 78 lines for a strategy for the CSS Debugging task, with a median length of 34 lines. Inspecting each of the strategies, we extracted the sub-goal each group of steps in the strategy was trying to achieve, finding that strategies consisted of four main elements: enumerating potential issues to investigate, determining if the issue applies to the situation at hand, offering a solution plan for addressing the issue, and applying it to edit the code. Some strategies included all of these elements,
(a) An authored strategy that does not cover exceptional conditions and edge cases

1. **This Strategy helps identify the origin of the CSS issue**
2. **Required Tools and Environments**
   1. IDE like Atom, Visual Studio Code 2. Browser
   3. Required Knowledge
      - Fundamentals of CSS, Browser Developer Tools
   4. **STRATEGY CSS DEBUGGING**
      1. Use Inspect feature of the browser of your choice.
      2. Once you click on Inspect feature, you can point to the section of your webpage that has CSS issue.
      3. The right-side corner of the Developer Tool window highlights the CSS used. You can change the CSS and see the changes on the webpage instantly.

(b) An authored strategy that covers multiple exceptional conditions and edge cases

Fig. 6: Two examples of authored strategies for the CSS debugging task.

while others included only some. In the strategy in Figure 6b, all four main elements are included.

To characterize the ways in which authors chose to express strategies, we identified a set of dimensions along which strategies varied. To do so, three authors and one collaborator first separately examined all of the strategies to inductively identify dimensions. These dimensions were then combined, where
the three authors and collaborator discussed the relationships between dimensions and merged similar dimensions. From this, we identified 8 dimensions, which we discuss below.

### 4.1.1 Rationale

Strategy authors varied in how much detail they chose to express in describing why each step of the strategy needed to be performed. Offering rationale explained why each step was necessary and the larger goal that sequences of steps were attempting to achieve. Some strategies included no explanation of rationale whatsoever, while others included extensive discussion. For example, Figure 7 lists a section of a strategy in which the author included a comment to explain the goal behind each group of steps. In contrast, in the strategy in Figure 6(a), the author chose not to include rationale, but instead only included a high-level description of the steps a user should take.

```plaintext
FOR EACH 'frontEndFile' IN 'frontEndJsFiles'
    # When looking for below error sources, aim for capturing generally likely sources of error
    # rather than exhaustively seeking every single potential source
    # STEP 1: Looking for potential errors in sources of input
    Look for UI elements that depend on user input, then ensure they are validated
    Look for both asynchronous and synchronous requests for data or input
    Look for blocks of code that convert data formats, such as importing configuration data
    # STEP 2: Looking for brittleness and hard-coded values
    Look for hard coded variable values, such as numerical constants
    Look for hardcoded style adjustments, such as setting a div to have an inline block style
    Look for repeated blocks of code that could be turned into functions
    # STEP 3: Looking for unfilled error handling steps
    Ensure that try-catch statements contain more than TODO in the catch section
    Look for unfulfilled TODO comments
    # STEP 4: Complicated functions
    Look for function signatures with many arguments, and read code to find each usage
    Look for very long functions, to see if you can make code more modular
    Look for deeply nested conditionals or for-loops
```

Fig. 7: Some strategies included rationale using comments (gray lines beginning with a hashtag).

### 4.1.2 References

Strategy authors differed in how many references to prerequisite knowledge, tutorials, tool specifications, and tool delegation work they included. Some authors explicitly identified prerequisite knowledge necessary to use the strategy (e.g., the first lines in Figure 6(b)). Having this knowledge before using the strategy might help users to understand the suitability of the strategy for their problem. Authors also sometimes described the extent that a strategy is tool-dependent, referencing a specific tool rather than a general category of techniques. Some authors referenced tutorials to provide instruction on how to gain prerequisite knowledge or learn to use the required tools. This included providing links to outside materials as well as describing how to use the tool to do the strategy’s steps.
4.1.3 Detail

Authors varied in the extent to which they elaborated or clarified descriptions of steps for users that might need more detail. Rather than include details in the statements themselves, some used comments. Separating details into comments could help users to save time by skipping the detailed description, if they do not need it. Other strategies included less detail (e.g., Figure 6(a)).

4.1.4 Machine Delegation

Some authors used Roboto’s support for sub-strategies or looping through lists, reducing users’ need to monitor their progress using a strategy. Some authors delegated tasks to the machine by defining loops or sub-strategies. To use loops, author recorded separate scenarios in a list, which were then used later to perform similar actions on each defined scenario.

Authors also varied in their use of persisting state by defining variables. Persisting information using state could help the user delegate the burden of memorizing required information for future steps they will need to do to the computer. For example, line 3 of the strategy in Figure 8 delegates persistence to the machine by recording information in a variable, ‘error-to-handle’, and then handling each scenario separately.

```latex
\begin{verbatim}
STRATEGY IdentifyAndHandleErrors()
    # Identify the errors, keep track of them
    SET 'errors_to_handle' TO IdentifyErrors()
    # Add error handling for them
    FOR EACH 'error' IN 'errors_to_handle'
        DO HandleError('error')

STRATEGY HandleError('error')
    IF 'error' can be prevented
        Update code to avoid error state
    IF 'error' cannot be prevented
        IF 'error' is confusing to user
            Update UI to explain the error to user
        IF 'error' locks up the UI
            Update component to reset UI or refresh page
\end{verbatim}
```

Fig. 8: An authored strategy that delegates work to the machine by storing information in a list, ‘error-to-handle’, and iterating over its contents.

4.1.5 Coverage

Authors varied in their level of generality, abstraction, and coverage of alternative scenarios and edge cases. Strategies differed in the number of different problems the strategy tried to solve, the scope of the problem the strategy covered, and the level of dependency of the strategy to a specific context, language, environment, or platform. Strategies also varied in the number of
exceptional conditions they covered. Some considered and checked for many edge cases, while others instead gave a broad overview of the steps that should be taken by the user without considering any exceptional scenarios. Figure 6 shows examples of two strategies written for the CSS debugging task. In the first (a), the strategy considers only one scenario that might occur. In the second (b), the strategy considers several scenarios, using conditionals to consider separate cases. Explicitly testing for exceptional conditions may help the user to use the strategy more quickly by skipping steps which do not apply.

4.1.6 Relevance

Authors differed in their understanding of the goal of the task and the steps they believed to be necessary to include to achieve this goal. For example, one author of the strategy for the CSS debugging task in Figure 9 included steps asking users to install Git, login to a GitHub account, and commit their changes. Interacting with a version control system might well be steps some users might take in some situations when debugging CSS. But in other situations users might choose not to immediately commit their changes or might use an alternative version control system, making these steps irrelevant to the user’s goal.

Fig. 9: An authored strategy with irrelevant steps.

4.1.7 Syntax

Authors chose different syntax in authoring their strategy, either by following Roboto syntax or using natural language. Figure 8 shows a sample of strategies written with Roboto syntax, while Figure 6(a) shows a strategy written in natural language.
4.1.8 Setup

Some authors included additional steps to set up and configure tools used in the strategy before addressing the main goal. For example, in the strategy in Figure 10, the author described how the user can make sure that the Chrome Developer Tools are ready to be used for the task.

```plaintext
# This strategy helps you to identify performance issues using the chrome profiler.
# Required tools and environments:
# Install chrome
Verify Chrome developer tools are enabled
Verify that you can open Chrome developer tools by pressing F12 on any web page
Navigate to the application to profile
# Required knowledge
General understanding of JavaScript and HTML Concepts
Familiarity with navigating the HTML DOM and
Strategy
ProfileApplication()
Open the web page to profile in Chrome
IF developer tools are not open
Open Chrome developer tools by pressing F12
Open the Performance panel in your developer tools
Start the recording by pressing the "Record" button
```

Fig. 10: An authored strategy which directs the user to set up and check if the Chrome browser and developer tool are ready to be used.

4.2 RQ2: Challenges Authoring Strategies

To understand the difficulties authors may face in expressing their tacit knowledge as strategies, we analyzed the 296 free responses given by authors in phase one to prompts to reflect on the challenges they faced in authoring. To analyze this data, three authors first each separately read all of the authors’ responses and inductively identified difficulties. To aggregate codes, the authors discussed the relationships between codes and merged similar codes. Based on these final codes, the authors then discussed instances where they disagreed on the code. Finally, the authors categorized related codes into several larger categories. From this, we identified 25 difficulties across five categories: finding the right scope, how to approach writing a strategy, using the Roboto strategy language, the effort required, and taking the user’s perspective. In the rest of this subsection, we discuss each of these five categories.

4.2.1 Finding the right scope

Authors reported six challenges related to finding the right scope for their strategy (Table 3). Some authors found it hard to articulate their strategy in a general way that was suitable for every task and users of varying expertise while keeping the strategy comprehensive and detailed. Authors also found it hard to keep the strategy abstract and imagine the range of scenarios it should cover. Some authors reported that writing a strategy for large and complex problems, testing the strategy, and deciding when a strategy is complete are
| Difficulty     | Description                                                                 | Authors’ quote                                                                 |
|---------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Abstract      | Challenges imagining the range of scenarios to cover in a strategy          | “I had to think about the scenarios I run into and then try to write something which is generic enough without knowing the problem.” (A1) |
| Generalization| Concerns about strategies being too general to be helpful or too specific to be relevant to many cases | “It’s much easier to write the strategy if the problem statement is more specific, and in a specific programming language.” (A6) |
| Completeness  | Being consistent, structured, and planned, and not forgetting steps that are habitual and tacit | “Many aspects should be taken into considerations. Ignoring or forgetting a small steps may make the whole strategy pointless.” (A14) |
| Scalability   | Scaling to large and more complex problems, which may make strategies hard to understand and use | “Strategies can end up being too long for complex problems.” (A14) |
| New Information| Responding to new information during the task                              | “Strategy keep[s] evolving based on the difficulty of task at hand.” (A2) |
| Testing       | Ensuring the strategy works well in all cases                               | “It’s hard to know how one would safely conclude they’ve tested for all possible errors.” (A11) |

Table 3: Authors reported difficulties in finding the right scope of their strategy.

challenging. Another difficulty was writing strategies in ways that appropriately responded to new information discovered during the task. We discuss two particularly interesting difficulties below.

1. Generalization: Some authors found it difficult to write the strategy in a way general enough to be helpful for the many differing tasks and situations or felt that their strategy was too specific to be applicable for different tasks. Some declared that making a strategy that is generally suitable for any programming task is very challenging, while domain specificity reduces these difficulties. As there are many tools, languages, environments, frameworks, technologies, and aspects that may vary across contexts, some believed that specifying a specific setting would simplify writing strategies. Two representative authors said:

“It’s hard to describe a strategy for something as abstract as ‘UI error handling.’ Without a clear description of what the UI is it’s hard to know what sort of errors to check for or how” (A11)

“While it wasn’t difficult to write a generic final statement, writing an informative or well-summarizing one seems tricky.” (A13)

These challenges were ultimately reflected in the differences between the level of coverage between strategies (Section 4.1.5).
2- Testing: Some authors reported that making sure that the strategy would be usable in all possible cases was hard. Authors reported that having a program on which to test their strategy might help make a better strategy by identifying missing steps, conditions, and details. For example, one author reported:

“Walking through the strategies multiple times to ensure that all broad categories of performance issues and types of slow activities were handled took a decent amount of effort.” (A15)

4.2.2 How to approach writing a strategy

Some of the strategy authors reported difficulties in how to approach writing a strategy. Table 4 enumerates the nine different challenges that we observed. These encompassed challenges with ambiguity in the task, how to articulate knowledge that is implicit and tacit, demonstrating the strategy to users without external resources or aids, how to effectively frame solving the problem, and expressing the right level of detail in the strategy.

Two of the challenges were particularly interesting.

1- Tacit Knowledge: Some authors found it hard to translate their thoughts into words, as it required them to recall strategies used in the past in different problem scenarios. Two representative authors said:

“I just need to remember all the situations I was in and how I resolved the issues.” (A2)

“It is hard because for many developers, we don’t spend time to write instead we are focusing more in coding. If we are in a meeting and explain the way we do things will much easier than write them out in a document.” (A10)

2- Level of Detail: Some authors found it hard to find and express the strategy with the right amount of detail for the level of user expertise. This mirrors the differences between strategies in the level of detail authors chose to include (Section 4.1.3). Two representative authors said:

“Having more examples targeted at various expertise levels would help.” (A9)

“To make the description easy to follow and understand, I’d probably be leaving out a lot of edge cases and essential information.” (A11)

4.2.3 Using the Roboto strategy language

Some authors who made use of Roboto as a syntax to express their strategy found it difficult (Table 5). Some reported that the novelty of the Roboto language made it hard to use. Others found it hard to express clearly in Roboto what they can express easily in natural language. Features that authors felt to be missing in the strategy editor made it hard to use for others.
| Difficulty                | Description                                                                 | Authors’ quote                                                                                                                                 |
|---------------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Tacit Knowledge           | Recalling strategies used in the past and translating thoughts into words     | “It’s much easier if its done in person or you are talking to that person over writing it down.” (A2)                                         |
| Organization              | Need for more strategy examples to learn how to correctly structure the strategy | “While the guidelines were helpful, I felt the example given was a lot more concrete than the one we were asked to write a strategy for and hence it was limited in how helpful it was.” (A11) |
| Unclear Task              | Unclear what the task asked them to write a strategy for                     | “I almost gave up on this a few times because it seemed so unclear what was being asked of me or how I’d even go about writing such a strategy.” (A11) |
| Process                   | Determining how to effectively frame solving the problem                     | “The instructions say not to include instructions on resolving the problem, but some level of resolution is necessary to make sure the change actually worked correctly.” (A9) |
| Usability                 | Assuring the authored strategy works well with real programs                 | “I think it provides a nice framework, but am not sure how well it would work in the real world for specific problems instead of generic concepts.” (A17) |
| Demonstration             | Illustrating the strategy without the ability to demonstrate it on a real programming task or supporting tools for communicating necessary concepts | “In person explanation probably is better by going over debugging strategies using live examples and demonstration” (A2) |
| Choice and Repetition     | Articulating reasons for making specific choices between alternative approaches and capturing similar aspects in the strategy to reduce repetition | “Once I hit a point where there are many directions to investigate it is more difficult to explain my thinking.” (A12) |
| Level of Detail           | Finding and expressing the right level of detail to explain strategy adequately | “It’s been a long time since I was a "novice" developer and I don’t look at a single guide to do anything, I normally piece information from various sources as well as my experience together, so it’s hard to know how much detail or not to include.” (A9) |
| Tool Use                  | Communicating necessary terminology and concepts for using referenced external tools | “It’s easy to look at the Profiler and know what’s happening but it’s hard to explain it.” (A3)                                               |

Table 4: Difficulties in how to approach writing a strategy.
| Difficulty       | Description                                                                 | Authors’ quote                                                                                     |
|------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Expressiveness   | Missing language constructs required to express strategy in way that is clear and concise | “I wish there was more coded syntax. It was a bit too much like pseudo-code in that I felt I can make up syntax.” (A17) |
| Novelty          | Novelty of using Roboto                                                     | “Using Roboto is new. I need to get used to it.” (A7)                                               |
| Formal Notation  | Expressing ideas that are simple to say in natural language more formally in Roboto syntax | “It gives it a standardized and structured format which could be easier for any developer to follow. They need to be familiar with some programming style though. For example, a developer who mainly works with HTML and CSS may not quickly grasp the syntax and format mentioned for Roboto strategy.” (A1) |
| Authoring Tools  | Missing support in the strategy editor for syntax highlighting, code formatting, signalling line breaks, toolkits | “I wish there was more coded syntax. It was a bit too much like pseudo-code in that I felt I can make up syntax.” (A17) |

Table 5: Difficulties using the Roboto language.

| Difficulty       | Description                                                                 | Authors’ quote                                                                                     |
|------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Time             | More time consuming than verbal communication                               | “It takes time to write something down in a proper, structured format over just talking to someone or even writing it down based on the exact issue.” (A1) |
| Concentration    | Cognitively demanding task which requires freedom from distraction and could be frustrating and mental exhaustive | “It needs an understanding of the problems. Asking 3 core questions in any strategies. Why What and How. Concentration to keep the key points. The effort to make sure all the use cases are addresses and energy to keep the team going.” (A4) |
| Not Interesting  | Not viewed as a fulfilling and enjoyable task                               | “I wouldn’t want to do this for my job.” (A3)                                                     |

Table 6: Difficulties concerning the effort required to write a strategy.

4.2.4 The effort required

Some authors found it hard to write strategies due to the time and effort required (Table 6). Some reported that writing a strategy down was more time consuming than verbal communication. Others reported that it required intense focus and concentration. Some felt that this work was inherently boring.
4.2.5 Perspective taking

Some authors reported challenges with perspective taking. Some authors found it hard to pick an expected level of knowledge for the strategy user and ignore their own level of knowledge. Authors reported difficulty guessing what would be the first question a user might have in using their strategy and including an appropriate description. Authors believed that the appropriate strategy is very dependent on the user’s level of experience. Two representative authors said:

“It’s very difficult to know if somebody else would understand the instructions.” (A9)

“Some problems/programming scenarios have multiple layers of complexity. To write strategy for novices, these complexities must be abstracted but it should also make sense. Achieving this balance is difficult.” (A18)

4.2.6 Positive feedback

Among the difficulties authors reported, some authors included unsolicited positive feedback about their experiences writing programming strategies. For example:

“It helps to communicate problems more clearly. Shows experience, makes us think out of [the] box.” (A4)

“It is a new idea and it can be effective.” (A8)

“It helped me think what I should do for my work project.” (A10)

“It is in fact interesting, as it made me realize my process. Many crucial steps are instinctively done and can easily be looked over during the documentation process.” (A18)

Some of the positive feedback focused on the Roboto language:

“Roboto gives it a standardized and structured format which could be easier for any developer to follow.” (A1)

“Roboto language can make it more opinionated to write strategies. It is some kind of standardizing for writing strategies.” (A8)

“The language seems pretty well featured.” (A13)

“Expressing conditional branching and looping in normal English language can be messy in comparison to Roboto’s IF and WHEN statements.” (A15)

“I do not find it particularly challenging to write a profiling strategy since I was able to write it as though I was speaking to an experienced web developer. The most challenging part is handling all the conditional branching involved in a strategy. I like that Roboto provides a way to do that.” (A15)

4.3 RQ3: Challenges Using Strategies

To characterize the difficulties developers face in using authored strategies, we analyzed the 150 comments we received from users. Three authors separately examined the users’ responses and inductively identified a code for each response as a representation of the user’s difficulty in using a strategy. The
generated codes were combined, with three authors discussing the relationships between codes and merging similar codes. Finally, the generated codes were clustered into groups. This process yielded 12 codes and two groups: difficulties using strategies related to strategy concepts and difficulties related to the user’s level of knowledge.

4.3.1 Difficulties understanding and using strategies

Users reported challenges related to understating and using strategies (Table 7). Some found it hard to understand what the strategy asked them to do and the relationship of this to the overall goal. Some users needed a more precise description of how to take a step in the strategy. Some reported that they needed to read the strategy multiple times to understand what it asked them to do. Other users had challenges understanding if the strategy would work for the programming task they had in hand, as the strategy did not support covering relevant edge cases. Below, we discuss a few challenges that are more connected to the challenges that authors had in more detail.

1- Imprecise Steps: Some users reported needing more detail to understand how to perform a step in the strategy. For instance, some users reported that they needed more information on what they should refer to in the code and how to accomplish the action. This challenge mirrors the differences between the level of detail authors included (Section 4.1.3) and the difficulties authors had in choosing the right level of detail (Section 4.2.2).

2- Tool Use: Some of the users found it hard to use a required tool to perform the described action. They particularly had problems finding the described functionality in the tools the strategy instructed them to use. This challenge reflects the difficulties authors experienced in describing the Tool Use actions that they wished the user to take (Section 4.2.2).

3- Ambiguity: Some users expressed confusion understanding the rationale behind performing actions in the strategy. They reported being confused about what each step tried to accomplish and why it is necessary to achieve the goal. This mirrors differences between authors in the amount of rationale they chose to include (Section 4.1.1). Other users were confused about the terminology that authors used in the strategy. In other cases, there were errors in the strategy. In one instance, a user got confused by a strategy which invoked a sub-strategy which was never defined.

4.3.2 Difficulties with prerequisite knowledge

The second group of difficulties reflected a mismatch of the strategy to the knowledge level of the user (Table 8). Some users had more experience and knowledge than the author of the strategy and suggested a better strategy or step for accomplishing the same task. In contrast, some users had insufficient experience and felt that the strategy was not descriptive enough for them and required more description. These challenge mirrors differences in the level of
| Difficulty       | Description                                                                 | User’s Quote                                                                                                                                 |
|------------------|-----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Imprecise Steps  | Need for more detailed description of some steps.                           | “Some explanation on how to debug edge cases could make it easier to follow, like how to debug animated elements or how to debug when element’s style is manipulated with js. Also, debugging on inline styling could be helpful.” (U6) |
| Tool Use         | Determining how to use a tool to perform the described action, particularly finding a specific referenced functionality in the interface or understanding how to use it | “Like the simple instruction given for opening the chrome developer tool (pressing F12), I was looking for something to teach me how to use the recorded files in order to find and fix the issue.” (U10) |
| Rereading        | Need to read strategy multiple times to understand                          | “I did not know how to use Performance profiler so I had difficulties figuring out the current frame state, network requests, animations but when I followed it twice, I was able to get it.” (U1) |
| Missing Steps    | Missing instructions or steps to solve the problem.                         | “The following is missing 1. Make changes and see if they are appropriate. 2. Take those changes and make it back in the IDE.” (U1) |
| Ambiguity        | Difficulty understanding the rationale of why a step is required to reach the goal | “In the expert strategy section, there are two points [not] explained. It’s not clear are they related to each other or both are different things.” (U8) |
| Unfamiliar Terminology | Using unfamiliar words in the strategy without a definition or description | “The strategy is not very clear as it is not very specific in terms of what part of the code to check or how to implement certain strategies such as a ‘logical flow’.” (U7) |
| Unclear Pre-conditions | Need for more detailed description of what is required to use the strategy | “I think more specific context regarding the preconditions and statements would be better.” (U5) |
| Generality       | Inapplicability to specific contexts, situations, or edge cases             | “More description on what part of the code should I check and what are most probable places for errors happening—? Edge cases should be described to cover and not being missed.” (U12) |
| Environment      | Better environment for reading strategy, including syntax highlighting       | “I believe that color-coding... would be more suitable in order for one to better understand and follow this strategy.” (U5) |

Table 7: Strategy users reported challenges understanding and using strategies.
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| Difficulty       | Description                                                                 | User’s quote                                                                 |
|------------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Inefficient      | More effective ways to accomplish the strategy goal than that described.    | “The instructions and details are kinds of too much and also to mention there should be minor changes like chrome developer tools short-cut (ctrl+shift+I), etc.” (U14) |
| Unfamiliar       | Lack of familiarity with the concepts used in the strategy                  | “I was able to understand this strategy and task as I used the similar strategy "hovering over the defected html element" using inspect element. It usually helps identifying and resolving the CSS issue.” (U8) |
| Inapplicable     | Using a strategy that does not address the problem.                         | “I wasn’t able to change the background color to a random color using this strategy, since it’s CSS specific and I think that would need to happen in the JavaScript to set the CSS. However, this can help narrow down which style piece needs to be adjusted to set a color like that.” (U3) |

Table 8: Users faced challenges due to differences between the knowledge assumed by the strategy and their own level of knowledge.

detail included by different authors (Section 4.1.3) as well as the challenges authors reported in finding the right level of detail (Section 4.2.2).

4.4 RQ4: Challenges Revising Strategies

After users’ comments on their difficulties were returned to the strategy authors, strategy authors were asked to reflect on how feasible the issues would be to fix and what they believed had caused the user’s challenges. To understand these issues, three authors separately generated codes for all the authors’ responses and inductively generated a code for each response. Similar to the analysis for the first and second phase, paper authors collated all codes, merged similar codes, discussed differences between codes. This process yielded a set of 8 codes.

4.4.1 Constructive, comprehensive, and helpful feedback

Some of the authors found some feedback constructive, comprehensive, and helpful. Some authors agreed with the limitations users reported, agreeing that their strategy was not sufficiently comprehensive and should be improved. For example two authors said:

“Yes. It’s a fair criticism and a weakness in the strategy of which I was already aware.” (A5)

“Yes, this comment makes sense - the reviewer included the instruction in the feedback.” (A8)
In other cases, authors felt that the goal and scope of the strategy they wrote was not well defined, leading to a mismatch between what they wrote the strategy to do and what the user expected. They concluded that offering an example of a step or visually presenting the step through an image would offer clarification and make the strategy easier to follow. One author reported:

“I did not consider all the different sections the user would be looking for. There are a lot of sections in the profile so it could be challenging and time consuming to consider every deviation.” (A3)

4.4.2 Incorrect usage

While some authors agreed with comments, others disagreed with user comments, viewing them as reflecting a mistake a user made in using the strategy or a misinterpretation of statements in the strategy. Some authors reported wanting a screenshot of users’ work to help them understand what the user was doing and where they were getting stuck. One representative author responded:

“Yes, the first part of this comment is not valid because the tester missed reading the comment for all css files. The second part also might have been misunderstood by [the] tester.” (A14)

4.4.3 Generalizability

Some authors realized that the context for which they were writing the strategy differed from the context in which the user was using the strategy. This might occur from a tool that did not support the necessary steps. Some authors also understood that the goal and scope of the strategy they wrote was not well defined, leading to a mismatch between what they wrote the strategy to do and what the user expected. Authors found some comments about the expectation of the user to have a strategy that works for all possible similar problem scenarios. It was hard for authors to devise a strategy that describes what to do in every possible situation when there were many possible problem scenarios. Finally, some authors felt that they could not provide more details without reducing the generality of their strategy, and the user’s request to change the strategy to cover many specific scenarios would cause a loss of generality. One author stated:

“I felt that the original assignment asked me to be generic as possible. I could not be more specific without knowing the language (or at least family of languages) used, and especially without knowing the architecture. If I were to assume a specific architectural context, and ask a more specific question, a less experienced developer might have answered "No, I don’t have one of those" when in fact they had a logical equivalent for their ecosystem. This is a problem that also happens in the real world. Gaining context about the exact problem being solved is key when mentoring a less experienced programmer.” (A5)
4.4.4 Unneeded or unrealizable situations

Some authors reported that some users’ comments asked for a strategy to address situations or contexts that cannot occur and were not necessary. For example one author stated:

“IT tells me that the reader is not a web developer and not familiar with web control object like list-boxes (drop down list boxes) and the term alpha for alphabetsical. Web application[s] do not take symbols as input... as most user[s] are not aware of the extended ASCII set and more text boxes (or textareas) like the one I am entering this text in now, will not access the keyboard entry of Alt-214 for the alpha character.” (A7)

In other cases, users wanted a strategy to offer support for making a decision at a point in the strategy where there was not yet information available to make this decision.

4.4.5 Mismatched level of knowledge

Authors sometimes realized that they had misjudged the user’s prior knowledge. Authors found it difficult to write the strategy without knowing the user’s level of knowledge. Assuming background knowledge made some steps easier to understand or unnecessary to explain. Some authors stated that users should have been able to gain background knowledge through their own investigation rather than through the strategy itself. One author responded:

“Debugging is not solely and purely related to CSS anymore and it requires some debugging knowledge of JavaScript.” (A8)

4.4.6 Hard-to-address feedback

Some authors viewed some of the users’ feedback to be hard to address. Some reported that some aspects of the strategy were hard to explain or would take too much time. Other requests were impossible to satisfy given the limitations of the strategy editing environment, such as requests for syntax highlighting or adding links to images.

4.4.7 Resistance to increasing detail

Some users requested wanting additional detail about specific strategy steps. Authors sometimes reported that adding these details would make their strategy too long and harder for users to follow, signaling the tension between detail and level of expertise. For example, one representative author said:

“It is hard to write [a] set of instructions so thoroughly to address all types of scenarios in simple words so everyone can understand, specially in the first try.” (A8)
4.4.8 Ambiguous feedback

Some authors felt some comments left ambiguous exactly what the user requested. Authors often found broad requests for additional detail to be excessively vague. For example, one author wanted a more concrete example of the types of detailed information the users requested to include or the exact line number in the strategy where the user had gotten stuck. One author said:

“I think not being specific and providing enough details in the comment about why the strategy action was ambiguous and didn’t make much sense to them makes it hard to address. If the tester had specified why it doesn’t make much sense, it could have been easier to address.” (A1)

In other cases, users used a term or made a reference that the author did not understand. Some authors had difficulty understanding how the user was interpreting a statement. In cases where the authors found feedback ambiguous, some proposed including a screenshot of users’ work to help them understand what they were doing and where they were getting stuck.

5 Threats to Validity

As with any study, our study design had several important threats to validity.

There were several potential threats to construct validity in our study design. First, because there are no widely accepted measures of prior knowledge in programming, the expertise of authors might have been more variable than intended. This might have led some developers to write strategies for tasks for which they had little expertise. Second, the participants self-reported their challenges after they completely finished using the strategy. It is possible that authors forgot some of the challenges they faced after they finished writing the strategy, or misremembered them when reporting them. An in-person study might have produced different results, allowing for think aloud data and communication with participants to extract more data.

From an internal validity perspective, our study design had several gaps. We did not directly observe users as they worked to examine how closely or carefully they followed the strategies they were given. For example, one trade-off of not observing the users is that when a developer has better information than the strategy, a user might abandon performing the actions the strategy asked them to perform. So, a user might instead guess what could be difficult about using the strategy and critique the strategy by comparing it to the strategy that they believe is more effective. When a user got stuck in a step in the strategy and needed to perform an action in order to proceed, the user could give up continuing using the strategy. This would result in not collecting difficulties other users who progressed further might have experienced. In our design, authors were asked to author a strategy for a specific type of task, which users then performed. We did not examine any potential difficulties of identifying or choosing between relevant strategies for a specific task. Some participants were unfamiliar with the concept of a strategy, and we therefore
provided training materials. While more experienced developers might not need this training, inexperienced developers might have benefited from further training, which might have reduced the difficulties they experienced.

There were also several potential threats to external validity. In attempting to simulate the characteristics of a platform for sharing strategies that did not yet exist, the ways in which users and authors interacted might differ from the ways in which users might interact in a real world platform. Users might experience difficulties that they did not experience in our study when working with larger and more challenging programming tasks. Platforms might incorporate different mechanisms for feedback, such as multiple rounds of interactions between authors and users or different ways of incorporating feedback. Our results are thus limited in partially reflecting characteristics of the specific platform we simulated.

6 Discussion

Our analysis revealed that experienced developers can in fact explicitly articulate their strategies, suggesting that programming strategies are not tacit. However, while developers were successfully able to write down and externalize strategies which existed in their heads, our results show that authors faced many challenges in translating these into a form usable by other developers.

These results offer some of the first evidence of the feasibility of explicitly sharing programming strategies. But the results also suggest the need for substantial tool support for writing strategies and extensive opportunities for strategy users to offer feedback in order to produce strategies of high quality for diverse developer audiences. Our work therefore builds upon the promise of using explicit programming strategies to improve developer productivity [22,10,47], suggesting a number of challenges which future knowledge sharing platforms need to address to effectively facilitate strategy authoring and use.

Our results suggest a number of ways in which these challenges might be addressed. For example, our results identified 8 dimensions along which developers vary in their choices in how to articulate strategies. Future strategy sharing platforms should support authors in helping to consider these dimensions when writing down their strategies, such as by providing feedback and suggestions from users along these dimensions and by offering reminders and explicit guidance. For example, a sharing platform might include some of these dimensions in a checklist, asking authors to consider how to set up any referenced tools, check for irrelevant steps in the strategy, consider how many edge cases to cover, or suggest asking users to write down information for later use. Explicit guidance might also be given to address difficulties in how to approach writing a strategy.

Some challenges may be addressed by offering better editor support for working with strategies and better support for developers in using strategies. Our findings suggest that authors found it hard to communicate some concepts through text, and might benefit from other ways of expressing strategies with
more visual content or even video demos. A strategy sharing platform might offer authors the ability to better integrate and connect strategies to reference tutorial materials or demos, which might, for example, illustrate through a video how to perform a specific step with a specific programming tool. Enhanced strategy editor support could also better support authors in writing valid Roboto syntax, through syntax highlighting and error messages.

Our initial results also suggest a close relationship between several of the difficulties authors themselves experienced with users’ challenges in making use of strategies. This suggests that future strategy sharing platforms might consider how authors and users might productively interact to improve strategies over time. Authors faced many difficulties finding the right level of detail to include in the strategy, perhaps caused in part by the difficulties of ignoring their own knowledge and understanding exactly what a less experienced developer needs. The more users try to use the strategy, the more the strategy could be revised to handle the issues identified by users. Authors could improve their strategies to make them work for a variety of problems at different scales, contexts, and languages, helping authors to incrementally address challenges with abstraction, generalization, and scalability. Iterative collaboration between authors and multiple users could help in covering more possible edge cases and addressing missing steps. In other situations, where a specific strategy is not a good fit, such as when it is inefficient or inapplicable, feedback might help clarify when a strategy is an effective approach and invite new strategies to be created for situations in which it is not an effective fit. Feedback may also sometimes be contradictory, and platforms should help authors in choosing between conflicting feedback and helping them explain the rationale to all users for the approaches they have taken.

In making use of feedback from strategy users, strategy authors were able to understand some of the feedback they received and envision ways that they could improve their strategy. For example, a user’s comment about adding a missing step in the strategy helped in clarifying the strategy. In other cases, authors disagreed with the feedback. Authors disagreed with users’ feedback for several reasons. In some cases, authors felt that users had misused their strategy. In other cases authors realized that the context that the strategy is expected to be used in differed from the context in which the user was trying to use the strategy. Authors also found that they sometimes misjudged the users’ prior knowledge, requiring users to have knowledge they did not have. Some of this feedback may trigger revisions, such as clarifying its applicability and prerequisite knowledge. Some of these issues might not even need intervention from authors, as users might clarify through their own experiences what knowledge is required and then share this with others. This also suggests the importance of effective search, to help users identify strategies that both address their specific situation at hand including its context as well as their knowledge and expertise. In other cases, disagreements may reflect more fundamental differences, as in a case where a user believes that steps are inefficient or that they have differences of opinion with the authors in how best to approach a strategy. The suggests that the boundary between user and author
might sometimes be more fluid. The platform might, for example, let the user first suggest revisions to the author to accept or decline, and otherwise lets users fork and rewrite their own versions of strategies.

There are also a variety of important questions on how a user should request authors to write a strategy or to find an existing strategy. In requesting a strategy, it is important that the strategy effectively match the context and expertise of the user that requested it. To address this, a sharing platform might require information from the user, such as completing a checklist of knowledge in technologies, concepts, and skills or even require the use of knowledge assessments to more accurately assess levels of expertise. This information could also be incorporated into browsing or search interfaces, helping identify strategies at the right level of expertise for users.

7 Conclusion

In this paper, we explored the potential for experienced developers to author programming strategies reflecting their hard-earned expertise in tackling everyday programming problems. We found that experts can write down their programming strategies, suggesting that, at least for experienced developers, programming can be a self-regulated and highly conscious activity. However, we found that making this process work effectively is not simple, as both authors and users faced a wide range of challenges in communicating and using strategies. Our results suggest the importance of feedback, demonstrating the ways in which feedback might help authors in improving strategies. Future platforms for sharing programming strategies should explore ways to facilitate easy and constructive communication between strategy authors and users to help improve strategies and enable their use by developers of any expertise level. Overall, our work suggests opportunities for software engineering research to improve the effectiveness of software developers by not only developing better tools but also by helping developers create, share, find, and use effective strategies for the problems they face.

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References

1. Ames, C., Archer, J.: Achievement goals in the classroom: Students’ learning strategies and motivation processes. Journal of Educational Psychology 80(3), 260 (1988)
2. Bader, Y., Obeidat, B., Abdallah, A., Aqqad, N., Maqableh, M., Akhorshaideh, A.: The effect of intellectual capital on organizational performance: The mediating role of knowledge sharing strategy view project the effect of intellectual capital on organizational performance: The mediating role of knowledge sharing. Computer Science & Communications (2019)
3. Bakhuisen, N.: Knowledge sharing using social media in the workplace: A chance to expand the organizations memory, utilizes weak ties, and share tacit information. In: Unpublished Masters thesis (2012)
4. Baltes, S., Diehl, S.: Towards a theory of software development expertise. In: Proceedings of the 2018 26th ACM Joint Meeting on European Software Engineering Conference and Symposium on the Foundations of Software Engineering, pp. 187–200. ACM (2018)
5. Bass, L., Clements, P., Kazman, R.: Software Architecture in Practice, 3rd edn. Addison-Wesley Professional (2012)
6. Bock, G.W., Kim, Y.G.: Breaking the myths of rewards: An exploratory study of attitudes about knowledge sharing. In: PACIS (2001)
7. Böhme, M., Soremekun, E.O., Chattopadhyay, S., Ugherughe, E., Zeller, A.: Where is the bug and how is it fixed? an experiment with practitioners. In: Proceedings of the 2017 11th Joint Meeting on Foundations of Software Engineering, ESEC/FSE 2017, pp. 117–128. ACM, New York, NY, USA (2017). DOI 10.1145/3106237.3106255. URL http://doi.acm.org/10.1145/3106237.3106255
8. Cabrera, A., Cabrera, E.F.: Knowledge-sharing dilemmas. Organization Studies 23(5), 687–710 (2002). DOI 10.11177/0170840602235001. URL https://doi.org/10.11177/0170840602235001
9. Chau, T., Maurer, F.: Knowledge sharing in agile software teams. In: Logic versus Approximation (2004)
10. DeMillo, R.A., Pan, H., Spafford, E.H.: Critical slicing for software fault localization. In: Proceedings of the 1996 ACM SIGSOFT International Symposium on Software Testing and Analysis, INSTA '96, pp. 121–134. ACM, New York, NY, USA (1996). DOI 10.1145/229000.226310. URL http://doi.acm.org/10.1145/229000.226310
11. Falesi, D., Cantone, G., Kazman, R., Kruchten, P.: Decision-making techniques for software architecture design: A comparative survey. ACM Comput. Surv. 43, 33:1–33:28 (2011)
12. Felstowich, P.J., Prietula, M., Ericsson, K.: Studies of expertise from psychological perspectives, pp. 41–. The Cambridge Handbook of Expertise and Expert Performance (2006)
13. Finkel, M.A., Rugaber, S.: The value of slicing while debugging. Sci. Comput. Program. 40, 151–169 (2001)
14. Gamma, E., Helm, R., Johnson, R.E., Vlissides, J.M., Booch, G.: Design patterns: Elements of reusable object-oriented software. In: Design Patterns (1994)
15. Gilmore, D.: Expert programming knowledge: a strategic approach. In: Psychology of programming, pp. 223–234. Academic Press, London (1990)
16. Grant, R.: Toward a knowledge-based theory of the firm. Strategic Management Journal 17, 109–122 (1996). DOI 10.1002/smj.4250171110
17. Herbsleb, J.D., Moitra, D.: Global software development. IEEE Software 18(2), 16–20 (2001). DOI 10.1109/52.914732
18. Ipe, M.: Knowledge sharing in organizations: A conceptual framework. Human Resource Development Review 2(4), 337–359 (2003). DOI 10.11177/1534484303257985. URL https://doi.org/10.11177/1534484303257985
19. Jackson, S., Chinang, C.H., Harden, E., Jiang, Y.: Toward developing human resource management systems for knowledge-intensive teamwork. Research in Personnel and Human Resources Management 25 (2006). DOI 10.1016/S0742-7301(06)25002-3
20. Kavitha, R.K., Ahmed, M.S.I.: A knowledge management framework for agile software development teams, 2013 International Conference on Process Automation, Control and Computing pp. 1–5 (2011)
21. Ko, A.J., LaToza, T.D., Hull, S., Ko, E.A., Kwok, W., Quichocho, J., Akkaraju, H., Pandit, R.: Teaching explicit programming strategies to adolescents. In: Proceedings of the 50th ACM Technical Symposium on Computer Science Education, pp. 469–475. ACM (2019)
22. LaToza, T.D., Arab, M., Loksa, D., Ko, A.J.: Explicit programming strategies (2019)
23. Leonard Dorothy A., W.S., Barton, G.: Critical knowledge transfer: Tools for managing your company’s deep smarts. In: Harvard Business Review Press (2014)
24. Li, P.L., Ko, A.J., Zhu, J.: What makes a great software engineer? In: Proceedings of the 37th International Conference on Software Engineering-Volume 1, pp. 700–710. IEEE Press (2015)
25. Loksa, D., Ko, A.J., Jernigan, W., Oleson, A., Mendez, C.J., Burnett, M.M.: Programming, problem solving, and self-awareness: effects of explicit guidance. In: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, pp. 1449–1461. ACM (2016)

26. Mamykina, L., Manoim, B., Mittal, M., Hripcsak, G., Hartmann, B.: Design lessons from the fastest Q&A site in the west. In: Proceedings of the 2011 annual conference on Human factors in computing systems, CHI ’11, pp. 2857–2866. ACM, New York, NY, USA (2011). DOI 10.1145/1978942.1979366. URL http://doi.acm.org/10.1145/1978942.1979366

27. Mamykina, L., Manoim, B., Mittal, M., Hripcsak, G., Hartmann, B.: Design lessons from the fastest Q&A site in the west. In: CHI (2011)

28. McDermott, R., O’Dell, C.: Overcoming cultural barriers to sharing knowledge. J. Knowledge Management 5, 76–85 (2001)

29. McKeeachie, W.J., Pintrich, P.R., Lin, Y.G.: Teaching learning strategies. Educational Psychologist 20(3), 153–160 (1985)

30. N Suppiah, V., Sandhu, M.: Organisational culture’s influence on tacit knowledge sharing behaviour. Journal of Knowledge Management 15, 462–477 (2011). DOI 10.1108/13673271111137439

31. Panahi, S., Watson, J., Partridge, H.: Social media and tacit knowledge sharing: Developing a conceptual model. In: World Acad. Sci. Eng. Technol., vol. 6 (2012)

32. Parnin, C., Treude, C.: Measuring api documentation on the web. In: Proceedings of the 2nd International Workshop on Web 2.0 for Software Engineering, WebSE ’11, pp. 25–30. ACM, New York, NY, USA (2011). DOI 10.1145/1984701.1984706. URL http://doi.acm.org/10.1145/1984701.1984706

33. Polanyi, M.: The Tacit Dimension, pp. 135–146. Routledge & Kegan Paul (1997). DOI 10.1016/B978-0-7506-9718-7.50010-X

34. de Raadt, M., Watson, R., Toleman, M.A.: Chick sexing and novice programmers: explicit instruction of problem solving strategies. In: Australasian Conference on Computing Education (ACE) (2006)

35. Reber, A.S.: Implicit learning and tacit knowledge. Journal of experimental psychology: General 118(3), 219 (1989)

36. Robillard, M.P., Coelho, W., Murphy, G.C.: How effective developers investigate source code: An exploratory study. IEEE Transactions on software engineering 30(12), 889–903 (2004)

37. Roehm, T., Tiarks, R., Koschke, R., Maalej, W.: How do professional developers comprehend software? 2012 34th International Conference on Software Engineering (ICSE) pp. 255–265 (2012)

38. Shaw, M., Garlan, D.: Software Architecture: Perspectives on an Emerging Discipline. Prentice-Hall, Inc., Upper Saddle River, NJ, USA (1996)

39. Shen, X.: Developing country perspectives on software: Intellectual property and open source - a case study of microsoft and linux in china. Int. J. IT Standards and Standardization Res. 3, 21–43 (2005)

40. Singer, L., Figueira Filho, P., Storey, M.A.: Software engineering at the speed of light: How developers stay current using twitter. In: Proceedings of the 36th International Conference on Software Engineering, ICSE 2014, pp. 211–221. ACM, New York, NY, USA (2014). DOI 10.1145/2568225.2568305. URL http://doi.acm.org/10.1145/2568225.2568305

41. Storey, M.A.D., Singer, L., Cleary, B., Filho, F.M.F., Zagalsky, A.: The (r) evolution of social media in software engineering. In: FOSE (2014)

42. Stylos, J., Myers, B.A.: Mica: A web-search tool for finding api components and examples. Visual Languages and Human-Centric Computing (VL/HCC’06) pp. 195–202 (2006)

43. Sánchez, J., Sánchez, Y., Collado-Ruiz, D., Cebrián Tarrasa, D.: Knowledge creating and sharing corporate culture framework. Procedia - Social and Behavioral Sciences 74, 388397 (2013). DOI 10.1016/j.sbspro.2013.03.029

44. Treude, C., Storey, M.A.D.: Effective communication of software development knowledge through community portals. In: SIGSOFT FSE (2011)

45. Wang, J.K., Ashleigh, M.J., Meyer, E.: Knowledge sharing and team trustworthiness: it’s all about social ties! Knowledge Management Research & Practice 4, 175–186 (2006)
46. Woo, J.H., Clayton, M., Johnson, R., Flores, B., Ellis, C.: Dynamic knowledge map: Reusing experts’ tacit knowledge in the aec industry. Automation in Construction 13, 203–207 (2004). DOI 10.1016/j.autcon.2003.09.003

47. Xie, B., Nelson, G.L., Ko, A.J.: An explicit strategy to scaffold novice program tracing. In: SIGCSE (2018)

48. Zagalsky, A.: Beyond agile: Studying the participatory process in software development. CoRR abs/1705.05450 (2017). URL http://arxiv.org/abs/1705.05450